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ABSTRACT OF A REPORT

ON

SOLAR AND TERRESTRIAL MAGNETISM

IN

THEIR RELATIONS TO METEOROLOGY.

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BY

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF CHIEF OF WEATHER BUREAU,
Washington, D. C., November 1, 1897.

SIR: I have the honor to transmit herewith an Abstract of a Report on Solar and Terrestrial Magnetism in Their Relations to Meteorology, by Prof. Frank H. Bigelow, of the Weather Bureau, and recommend that it be published as a bulletin of the Weather Bureau.

Professor Bigelow has, during the past six years, devoted much time to the study of the fundamental principles of this important subject, and considerable discussion has ensued among scientific people in regard to the hypotheses assumed by him. He is of the opinion that the atmospheric conditions which culminate in the storms traversing the United States are in part dependent upon the solar energy that reaches the earth in the form of magnetic force; that there are synchronous fluctuations in the pressures and temperatures of the northwestern regions of the American continent in the neighborhood of the magnetic pole and the auroral belt; that a train of storms, "highs" and "lows," advance from that quarter eastward in well-defined tracks; that the position of the tracks and the intensity of the storms change along with the strength of the solar magnetic field; that there are many other forces at work to produce storms, such as the general circulation of the atmosphere and the local convection of heat and aqueous vapor, but that among them all must be included the magnetic forces in order to obtain a correct understanding of the mechanism of cyclones and anticyclones.

It is my opinion that at this stage of the investigation the sequence of cause and effect is not shown with sufficient definiteness to justify the weather forecaster in attempting, with our present knowledge of solar and terrestrial magnetism, to apply these theories to the making of forecasts and warnings of marked atmospheric disturbances. However, it is believed that the paper which Professor Bigelow presents will so stimulate thought and discussion as to result in further additions to the knowledge of magnetic science.

Very respectfully,

WILLIS L. MOORE, *Chief of Bureau.*

Authorized:

JAMES WILSON, *Secretary of Agriculture.*

PREFACE.

A remarkable feature of the history of terrestrial magnetism and also of meteorology is the fact that, in spite of many discussions of an enormous mass of observations, progress toward correlating them in general scientific laws has been very slow, the results in the main being unsatisfactory. The researches which I have conducted in these subjects have persuaded me that this has been largely due to erroneous points of view in two particulars. The first depends upon a premature rejection of the direct magnetic action of the sun upon the earth, as a working hypothesis; the second upon a too rigid application of the theory of the general circulation of the atmosphere over a hemisphere to the local cyclone in midlatitude zones. The authority given to these positions by their distinguished authors and advocates rendered it difficult to construct quite different plans of procedure, but it is believed to have been essential to do so in order to secure important advancement in these branches of science.

The exposition of these views embraces a series of papers arranged in parts.

I. Remarks on practical forecasting, which are embodied in Bulletin No. 20, United States Weather Bureau, entitled Storms, Storm Tracks, and Weather Forecasting, 1897, wherein the plan of the research is outlined in general terms.

II. Specific arguments and data in support of the doctrine of the direct magnetic action of the sun are contained in this Bulletin, No. 21, Abstract of a Report on Solar and Terrestrial Magnetism, together with their Relations to Meteorology, 1897.

III. Specific arguments and data in favor of the view that the fundamental equations of the general and the local cyclones are not strictly identical will be given in a paper, now in preparation, on the Circulation of the Atmosphere over the North American Continent.

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HISTORICAL INTRODUCTION. METHOD OF COMPUTING THE TERRESTRIAL MAGNETIC DEFLECTING VECTOR SYSTEMS.

That there is a causal connection between the observed variations in the forces of the sun, the terrestrial magnetic field, and the meteorological elements has been the conclusion of every research into this subject for the past fifty years. The elucidation of exactly what the connection is and the scientific proof of it is to be classed among the most difficult problems presented in terrestrial physics. The evidence adduced in favor of this conclusion is on the whole of a cumulative kind, since the direct sequence of cause and effect is so far masked in the complex interaction of the many delicate forces in operation as to render its immediate measurement quite impossible in the present state of science. Before attempting to abstract the results of this research on these points a brief résumé of the views held by the leading investigators will be given, especially with the object of presenting the status of the problem to those who are not fully acquainted with this line of scientific literature. The bibliography is large—covers a century—and embraces such names as Humboldt, Gauss, Sabine, Lamont, Faraday, Wolf, Ellis, Broun, Hornstein, Stewart, Schuster, Capello, Meldrum, Airy, Walker, van Bebber, Lemström, Fritz, Loomis, Kelvin, and many others.

CITATION OF OPINIONS AS TO THE CONNECTION BETWEEN CERTAIN SOLAR AND TERRESTRIAL PHENOMENA.

Walker expresses his conclusion regarding the main point as follows, page 103:[1]

> The almost exact coincidence, so far as hitherto observed, between the *periods* and *turning points* of three classes of phenomena at first sight so widely different, as the magnetic *disturbances*, the *diurnal range*, and the *frequency* of *solar spots*, can, I think, leave no reasonable doubt that this coincidence is *causal*, and not *accidental*. This fact, as Humboldt remarks, gives a very high cosmical interest to the study of terrestrial magnetism.

Lemström summarizes his own and current opinion in this way, page 24:[2]

> We borrow from Loomis a graphic representation of the phenomena, the number of auroras observed annually, the mean deviation of the magnetic needle, and the relative extent of the solar spots, which shows perfectly their accord from 1780 to 1870.

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[1] Terrestrial and Cosmical Magnetism, Adams prize essay, Walker.
[2] L'aurore boréale, M. Lemström, 1886.

The meteorological observations on which we can make computations embrace a period of time too short to enable us to establish with certainty the laws which regulate the changes of the atmosphere. But on comparing the observations of the perturbations of the atmosphere called cyclones or storms a periodicity is found which probably accords with the eleven-year period already mentioned. Fritz has indicated in his memoirs three remarkable results, which we will cite:

"1. During the time when the sun spots are at their maximum, the rainfall, snow, and hail are more abundant than during the time of minimum.

"2. The variability of the pressure of the air changes, also, in parallel with the great periods of the aurora borealis and the sun spots.

"3. Hurricanes and violent movements in the air are more frequent at times of maximum than at times of minimum spots, and on the other hand fair weather is more abundant in the latter case than in the former."

It is evident that if there is a close relation among these phenomena, it ought to be shown also in the quality of the harvests. (Compare Lemström's paper read at the Chicago Congress, 1893). We are then entirely in agreement with the general result of Fritz, that there is certainly a relation between the variability of the sun spots, the magnetic declination, and the number of the auroras; also, that similar relations with the meteorological phenomena are very probable.

W. J. van Bebber investigates carefully the meteorological side of the question with the following conclusion, page 258,[1] which is also quoted by Sprung in his meteorology, page 366:[2]

It appears to us undoubted that relations exist between the sun spots and meteorological phenomena, which if their characteristics and amount were known could be sometimes employed with success in our forecasts of the weather. It is probable that the periodic changes in the atmosphere are not brought about directly through the sun spots, but that both phenomena are produced by a common underlying agency whereby the synchronous variation in periods is possible.

He specifies such changes in the atmosphere along with the sun spots, as the temperature and pressure, cyclones and winds, precipitation, cloudiness, thunderstorms and hail, and concludes—

Therefore it is not to be denied that there is a connection between sun-spot frequencies and the changes in our atmosphere, only the periodic movement of the weather phenomena is beset by so many unknown kinds of disturbances that it is not now possible to make successful long-range forecasts from them.

Ebert introduces a section on "Magnetism as a cosmical force," as follows, page 55:[3]

We can not directly point out magnetic action of an extra-terrestrial source, but we recognize in the variable state of the body of our earth undoubtedly the play of cosmical forces. Especially, the so-called disturbances in the terrestrial system of the lines of force can probably be referred to the impressed action of the external heavenly bodies. Thus magnetism is a powerful cosmical bond which unites world with world.

The most comprehensive summary of the experimental and speculative aspects of the problem up to about fifteen years ago is to be found in the ninth edition of the Encyclopædia Britannica, article "Meteorology," by Balfour Stewart, where the complexity pertaining to the

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[1] Handbuch der ausübenden Witterungskunde, W. J. van Bebber, Stuttgart, 1885.

[2] Lehrbuch der Meteorologie, A. Sprung, Hamburg, 1885.

[3] Magnetische Kraftfelder, H. Ebert, Leipzig, 1896.

entire subject is presented to the reader. In order to concentrate our discussion, that article will be chiefly referred to as containing generally those views of the subject which it has been the object of this research to improve upon as far as possible. Our critical remarks are intended to be directed against these expressions by Balfour Stewart specifically only in so far as they broadly represent the opinions of investigators. After reviewing the evidence his final summary is, page 181:

On the whole, we may conclude that the meteorological motions and processes of the earth are probably more active at times of maximum sun spots and that they agree with the magnetical phenomena in representing the sun as most powerful on such occasions, although the evidence derived from meteorology is not so conclusive as that derived from magnetism.

REMARKS ON FOUR WORKING HYPOTHESES.

This is a fair, conservative estimate of the value of the data presented in preceding investigations. The problem now before us is to bring the subject one stage nearer to demonstration and also to extract a useful working process that will contribute to weather forecasting, especially for the United States. As preliminary remarks I make the following observations: There are four historical leading working hypotheses regarding the mode of the physical connection, during the synchronous states of the sun and the earth referred to above, namely, (1) the direct magnetic action of a solar field upon the terrestrial magnetic field; (2) assumed electric currents in the upper atmosphere, due to the convective currents of circulation; (3) Faraday's displacement currents of magnetism, due to the local and general heating of the oxygen of the atmosphere; (4) the thermoelectric currents in the body of the earth. It may be presumed that future discussion will be limited to the first and s cond views, namely, (1) the direct action of a solar magnetic field, and (2) the indirect effect of the radiation of the sun transmitted to the earth's magnetic field by convective air currents. Whatever truth may attach to the second view, the object of this paper is to uphold the first view as of primary importance. It is not, perhaps, possible now to discriminate accurately to what extent the second view expresses some of the facts of nature, but it is my judgment that the first view was prematurely rejected, in consequence of two or three papers written on the subject, and that the evidence in favor of it has not been suitably considered. It is one of the cases where observational data must outweigh academic discussion. Probably the apparent strength of the second view lies in the process of exhaustion, which, excluding the other theories, left it standing alone, although it may have, in fact, such arguments in its favor as entitle it to respectful consideration.

Balfour Stewart's careful summary of his knowledge of the variations of the terrestrial magnetic field produces upon the mind of the reader only a hazy conception of the causes at work, and shows that the sub-

ject needs further analysis for its satisfactory elucidation. This could long ago have been readily accomplished by constructing the systems of deflecting vectors operating upon the earth's field, as in this paper. The prevailing method of discussing the variations of the component magnetic elements one at a time, however, obscured the solution. The analysis in the following chapters shows that these disturbing vector systems are such as will be produced if the earth, as a permeable shell, is placed in two magnetic fields, with their axes at right angles to each other: (1) the first axis parallel to the ecliptic, and the field causing the diurnal deflections of the needle, as well as the annual changes by its movement in latitude along with the declination of the sun; (2) the second field being perpendicular to the ecliptic, primarily static and steady, but transmitting large and small perturbations, the great departures from the normal state of the polar field causing the observed disturbances at the several stations. Having these concepts in mind, it is easy to see that many of the perplexities that pervade Balfour Stewart's statement of the case readily clear themselves up, though it would require more space than is appropriate in this abstract to review each point in detail.

An effort must be made to counteract the arguments that have been widely accepted as conclusive against the hypothesis of the direct action of the sun as a magnet on the earth's magnetic field and as the true source of some of the observed deflections of the needle. It seems to be the best course to endeavor to supplement any arguments with such positive proof of direct action in our observed phenomena as will necessarily carry along conviction of the fact itself. The remainder of this paper apparently contains such a demonstration, and therefore renders further argument superfluous. But first it may be well to examine briefly the negative arguments which now stand in the way of the acceptance of this view as the proper explanation of some of the observed changes in the terrestrial magnetic field.

EXAMINATION OF FOUR ARGUMENTS USED AGAINST THE HYPOTHESIS OF THE DIRECT MAGNETIC ACTION OF THE SUN.

1. *Temperature argument.*—It is stated by Balfour Stewart as follows (Enc. Brit., p. 181):

> We have not advocated any direct magnetic action of the sun upon the earth, because from what we now know of the sun it appears to us unlikely that it should exercise an influence of this nature upon the earth, since a body at a high temperature possessing very strong magnetic properties is unknown to us.

It is evident that the *earth itself* was overlooked in this connection. According to received geological evidence, the interior of the earth is excessively hot, and yet a permanent magnetic field of considerable intensity is sustained by it, the field apparently having its seat in the material which constitutes the earth's nucleus. We shall show later on that the lines of the external fields in which the earth is immersed are

deflected around a large nucleus, and their configuration no doubt outlines the extent of the heated material. An ordinary steel magnet is merely an induced arrangement of molecules and does not exhibit exclusively all the possible magnetic states of the matter. There is no necessary inference to be drawn from common magnets, in their relation to temperature changes, that such primary bodies as the sun may not possess magnetic force among their potentialities, even at high temperatures. When the deflecting force of a magnet diminishes under an increase of temperature of the medium in which it is immersed the nature of the lines of force in the medium, as well as the molecular structure within the magnet, are to be considered. Whenever physicists explain the real nature of the ether stresses constituting a line of magnetic force we may take the next step in clearing up this difficulty. At present we know at least that an increase of temperature diminishes the strength of the magnetic field; on the other hand, that an increase of the strength of the field diminishes the temperature of the medium. The immediate line of argument followed in this paper is the simple fact that increase of strength of the solar magnetic field is accompanied by a lowering of the temperature of the atmosphere, and hence by an increased tendency to build high-pressure areas, in the convectional circulation, especially in certain well-defined polar localities.

2. The diurnal variations argument.—In the Phil. Trans. 1863, p. 503, Charles Chambers, in his paper "On the nature of the sun's magnetic action upon the earth," argues from the comparison of certain component forces derived from the sun as a magnet, with the observations at two stations, Toronto and St. Helena, that the evidence is against any appreciable direct action. (26.27). It may be pointed out in reply that the conception of the origin of the disturbing forces employed in that paper *does not apply to the diurnal variations at all*, because, as will be shown, the diurnal vector system depends exclusively upon the sun's electromagnetic or sunlight field, which is a radial field and apparently induces in the ether an efficient polarization, in respect to exploring magnets on the surface of the earth. Chambers thought that the diurnal variations of the needle and the disturbances had the same source; it is our purpose to show that they have different sources, and that the failure to explain the diurnal variation by direct action of the sun as a magnet is really no argument against such action if it shows itself as a different vector system. Hence the logic of that paper is in fault, if the position taken in this report is correct. Airy's conjecture of a "magnetical ether," (same vol. Phil. Trans., p. 646,) is much nearer the mark. Since Maxwell and Hertz have given evidence of the existence of such an electromagnetic field, the burden of proof is precisely the other way. We should expect to find marks of the action of this radiant magnetic field on the normal magnetic field of the earth, and my analysis of observations is wholly in accord with

such possible effects. The diurnal variations of the needle are not due to the direct magnetic action of the sun by means of an ordinary curved polar field, but they are the results of the stresses of the ether, polarizations or displacements, caused by the immensely rapid electromagnetic vibrations, whose magnetic induction integrates into a practically steady field, relatively to magnets of more than atomic dimensions.

3. *The argument that this hypothesis is unnecessary.*—Balfour Stewart says, in Enc. Brit., p. 181:

> In fine, without presuming to deny the possibility of unknown influences of this nature, it does not appear to us that the time has arrived when we are called upon to resort to such as necessary aids to the discovery of further truths.

This implies the consideration that the ordinary diurnal variations and the disturbances find their explanation in the assumed electric currents of the upper air, due to the convectional currents of the atmospheric circulation. We have to remark that the difficulty which he mentions in section 121 of conceiving such a system of currents as would account for the facts, is pushed to the point of breaking down this second hypothesis by the analysis of the following chapters. The systems of currents supposed by him in sections 125 and 132 can not be made to conform to the complicated requirements of the case. Considering the great complexity of the vector systems, taken separately, charts 8 to 16, inclusive, we have only to add that these must be superposed upon each other and accounted for together by the proposed system of electric currents. It will be shown in the last chapter that there is yet another important term to be introduced, namely, the periodic inversion of the deflecting forces, before the observed disturbances are fully explained. The needle experiences the diurnal deflection at any given station by the action of the electromagnetic vector system; this changes with the seasons of the year, because the aspect of the earth's field goes through an annual period relatively to the axis of the radiantly polarized ether; superposed upon this is the polar magnetic field, bearing the normal variations from longitude to longitude on the sun; likewise the great disturbances which widely deflect the needle, according to the usual laws of the composition of forces; finally, the annual change of the aspect of the earth's field to this polar magnetic field introduces a modification which will be considered under the subject of inversion of type. Now, when we attempt to refer the almost continuous fluctuations of the polar-magnetic field, with its minute interactions on the other fields, namely, the normal terrestrial and the solar electromagnetic at the several stations in each hemisphere, it may be said that anyone familiar with the facts will despair of locating the electric currents in the earth's upper atmosphere, capable of inducing these magnetic forces, not to speak of assigning suitable physical causes for the currents themselves.

This difficulty is greatly increased when we compare the electric currents equivalent to the given magnetic vectors, and which may possibly

be mapped out, with the observed currents of the meteorological atmospheric circulation. That some impulses derived from the systems of impressed external magnetic forces should exist within the earth's atmosphere, especially at the sensitive spots, is certainly rational; long continued and general movements of the air may correspond with the permanent conditions of the solar field; but to suppose such a vibratory atmospheric circulation as matches the quick periodic and aperiodic changes observed in the earth's magnetic field demands, at least, a specific description of the atmospheric currents involved in the operation. The more we pass from vague general ideas about these currents to details, the less appears the probability of the truth of the second hypothesis, as the cause of the phenomenon.

4. The intensity of solar magnetization argument.—The note by Prof. W. Thomson, Phil. Trans. 1863, p. 515, has been many times repeated in substance in various forms, namely, that any reasonable magnetization which can be assigned to the sun is incompatible with the effects observed in the earth's magnetic field, especially during disturbances.

Formula for equatorial force.

$$\left[F_e = \frac{4}{3}\pi \frac{R^3}{r^3} I, \text{ for } \theta = 90^\circ.\right]$$

Formula.	F_e	I	$\frac{I}{.079}$	$\frac{I}{1390}$	$r = 92,897,000$ miles. $R = 433,250$ miles.
Normal	0.00035	824	10430	0.59	$\left.\begin{matrix} \\ \end{matrix}\right\} \frac{r}{R} = 214.4$
Storm	0.00500	11768	148960	8.47	

The two cases of the normal field and the severe disturbances will be shown in the computations of chapter 4 to give, at the earth's distance from the sun, and for the sun's polar distance $\theta = 90^\circ$, $F_e = 0.00035$ and 0.00500 C. G. S., respectively. The magnetization of the sun by the usual formula as above is about 800 and 12,000 C. G. S., respectively; this is 10,000 and 150,000 times the magnetization of the earth; *only 0.6 and 8.5 times that of saturated steel.* The observations show that usually the magnetization of the sun is less than that of steel, but may become ten times as much in extreme disturbances. Professor Thomson said in the note referred to, "the sun's magnetism would therefore need to be 120 times as intense as the earth's to produce a disturbance of 1′ in declination even by a complete reversal in the most favorable circumstances." The observational data leads us to believe that the sun is continuously magnetized about eighty times as strong as this specified amount, and therefore we conclude that this negative argument is not such as to exclude the hypothesis of direct action. The upper limit, ten times that of steel, we need not reject as irrational. It may lead to some revision of current theories regarding the magnetic nature of solar material, but that is, under the circumstances, the most plausible course to pursue.

REVIEW OF THE STATUS OF THE EARTH MAGNETIC PROBLEM.

A brief review of the results of several recent discussions of the earth's magnetic potential may serve to exhibit more clearly the bearing that this investigation has upon the solution of the problem in general. Gauss made an important advance over his predecessors by applying the harmonic analysis to the distribution of the earth's potential. Approximate reproductions of the normal terrestrial magnetic field had been made (1) by substituting hypothetical, small magnets near the earth's center; (2) by the method of distributing magnetic material on the surface; (3) by the method of displacement, and (4) by the equivalent electric currents circulating around the magnetic axis. These suppositions approximated only roughly to the observed values of the magnetic forces. Gauss assumed that the earth has a magnetic potential, that it is heterogeneous, wholly within the surface and, carrying the solution to the terms of the fourth order, found a result in better agreement with the observations. (*Gauss.* Allgemeine Theorie des Erdmagnetismus, 1838.) After the lapse of thirty years Erman and Petersen availed themselves of the large number of additional observations which had been made, and repeated the harmonic computation along lines similar to that of Gauss. They hoped that a substantial improvement would be possible by the use of more accurate observational data, and in this they were partially successful. (*Erman* und *Petersen.* Die Grundlagen der gaussischen Theorie und die Erscheinungen des Erdmagnetismus im Jahre, 1829; Berlin, 1874.) The comparison is given in their Table 13 between the old and new theories, but it is clear that the residuals are still too large to be considered satisfactory.

The next advancement was made by Professor Schuster in his paper on the "Diurnal variation of terrestrial magnetism" (Phil. Trans. Roy. Soc. London, 1889), in which he modified the theory that the potential is confined to the inside of the earth and computed the potential of the disturbing forces of the diurnal variation on two suppositions, (1) that it is inside, and (2) that it is outside the earth. His conclusion is as follows, page 468:

The agreement seemed to me to be sufficiently good to justify the conclusion that the greater part of the variation is due to causes outside the earth's surface. * * * The results of the calculation point not only to an external source, but to an additional internal source, standing in fixed relationship to the external cause. This we might have expected. A varying potential due to external causes must be accompanied by currents induced in the earth's body, which, in turn, must affect the magnetic needle.

The author attributes this external potential to electric currents in the atmosphere, made possible by its being in a peculiarly "sensitive state." I shall venture to suggest one or two criticisms on this valuable paper: (1) Schuster depends upon four stations—Bombay, Lisbon, Greenwich, and St. Petersburg—for the coefficients of the diurnal variations, these belonging to the midlatitude belt, and having, *by chance*,

the same distribution of the *vertical* component. But by comparing my globe model (see chapter 4) with them, it is seen that the *total* vectors are quite differently disposed in the equatorial zone and entirely different in the polar zone from those in the midlatitude zone. In short, Bombay should not be included with the other stations in the same vector system. It appears, therefore, that his extrapolation from pole to pole, page 477 et al., was not proper, the reduction given being true for the midlatitude zones, north and south, and only approximately so near the equator.

On comparing his fig. 12, page 508, with the globe model, it is perceived that we have arrived at nearly the same distribution of the vertical components, after translating the stream lines of Schuster's current function into equivalent magnetic force; but the vectors are really very different, because the horizontal component is lacking in his diagram. There is, undoubtedly, an exceedingly close connection between the diurnal circulation of the winds and this magnetic distribution, as Schuster mentions, in the midlatitude and also in the polar zones. My belief is that this convectional circulation of the atmosphere is the cause of the shifting of the magnetic system from a symmetrical distribution about the noon meridian into the observed eccentric position. It might plausibly but incorrectly be interpreted as a lag angle due to the rotation of the earth. According to cloud observations, at the 10 a. m. hour there is formed a circulation like a high-pressure area, and at 6 p. m. another like a low-pressure, the winds circulating from the high to the low by two paths, the short one from west to east across the noon meridian, and the second by a longer path crossing the midnight meridian. The subject is interesting but difficult, and is reserved for further examination in connection with our cloud observations.

In order to account for the electric currents, Schuster works out another hypothesis, namely, the theory of the earth as a magnet rotating in a medium of electric conductivity, in Terrestrial Magnetism, vol. 1, p. 1, on "Electric currents induced by rotating magnets, and their application to some phenomena of terrestrial magnetism." The conclusion is that some evidence exists for the conductivity of the ether, and if this is the case it is in harmony with the observed phenomena of the secular variation of the earth's magnetism. Whatever truth may finally be awarded to these two working hypotheses of Professor Schuster, it is proper to state the position assumed in this bulletin as a substitute for them, especially as the theory of electric currents in the upper atmosphere is quite commonly adopted as the explanation of the observed phenomena. The actual facts can be accounted for either by an external magnetic field or by an equivalent system of electric currents. The variation of either of these systems of forces induces currents in the earth, which, in turn, affect the position of the needle. *My effort has been to endeavor to show that this external field has characteristics which are entirely incompatible with a field induced by electric*

currents whose seat is within the earth's atmosphere. The phenomena of periodicity in solar periods and of inversion of the typical curve semi-annually are regarded as evidence of this position. This thesis will be maintained in the following pages.

Adolf Schmidt has recently completed a rediscussion (Neue Berechnung des Erdmagnetischen Potentials, 1895) in which distinct provision was made in the harmonic analysis for (1) an inside potential, (2) an outside potential, and (3) for vertical earth-air electric currents. His conclusion is as follows, based upon the best series of observations available, and including harmonic terms of the sixth order:

Die empirisch festgestellte Verteilung der erdmagnetischen Kräfte in der Erdoberfläche, wie sie durch Dr. Neumayers Karten für den Augenblick 1885.0 dargestellt wird, beruht zwar vorwiegend auf Ursachen, deren Sitz im Erdinnern liegt, kann aber nicht ausschliesslich auf solche zurückgeführt werden. Ein kleiner Teil der Kraft (etwa 1-40 des ganzen Betrages) ist Ursachen ausserhalb der Erdoberfläche zuzuschreiben; ein weiterer, noch etwas grösserer Teil (auf eine Fläche von einem Quadratkilometer kommt daher durchschnittlich ein Strom von 1-6 *Ampère*) deutet auf elecktrische Strömüngen hin, welche diese Fläche durchdringen.

It may be noted (1) that Professor Rücker concludes his discussion of the results of the magnetic survey of Great Britain as follows: "The local magnetic surveys furnish no evidence of vertical electric currents in the United Kingdom" (Terr. Mag., Vol. I, p. 83); (2) that Dr. Bauer, from summations of magnetic circuits on the earth's parallels, the data being drawn from observations compiled into charts, finds, "apparently, an appreciable part of the earth's total magnetism can be referred to an effect similar to that of vertical electric currents. The average intensity of these currents for the region between 60° N. and 60° S. would be about one-tenth of an ampère per square kilometer of surface" (Terr. Mag., Vol. II, p. 21); (3) furthermore, Schuster remarks (Terr. Mag., Vol. I, p. 16):

If we could adopt Dr. Schmidt's numbers as final, they would show that the outside magnetic potential is displaced toward the *east*. Such an effect might be produced by currents induced in a medium rotating more rapidly than the earth, which might be the case if the upper currents of the atmosphere had a general drift from west to east. The displacement of the outside potential, according to Dr. Schmidt, is, however, greater than 90°, which is difficult to reconcile with the hypothesis of induced currents under any circumstances.

Dr. von Bezold attempted to analyze the earth's magnetic potential as a sine distribution about the axis of rotation. (Sitz.-Ber. Berlin, 1895, p. 363.) Dr. Schmidt concludes his examination of this question of distribution relatively to the rotational and other axes: "No argument favorable to the assumption can be drawn that the principal part of the terrestrial magnetic force stands in any relation to the rotation of the earth." (Terr. Mag., Vol. I, p. 27.)

V. Carlheim-Gyllensköld makes the following remarks regarding the origin of the disturbing forces in his paper "L'attraction magnétique de la terre," 1896:

Any complete theory of the magnetic attraction of the earth appears to be possible only on the condition that the observed effects result from a cause acting regularly

and continuously in the same manner (p. 29). In our view, the phenomenon of the secular variations of the magnetization of the earth is a great phenomenon of electro-magnetic induction operating in the rarefied layers of the atmosphere, put in motion by the rotation of the earth (p. 32). If the relative movement of the upper layers of the atmosphere is directed in the opposite sense to the diurnal motion, the observed movements of β_n^i conform to the theory.

It is, however, a well-known meteorological fact that the relative motions of the upper atmosphere are all eastward and not westward, as required by Gyllensköld's view.

In a more recent paper (Zur Theorie des Erdmagnetismus, 1897) von Bezold integrates through several circuits on the surface of the earth for vertical currents, and concludes that the errors of observation are such that the material affords only indecisive results (p. 5); that the great ocean areas preclude observations to such an extent as to invalidate the application of the method to a circle of latitude (p. 6); that when applied to small, well-surveyed circuits the departure of the sum from 0 is well within the limits of error of observation, being about 1 per cent (pp. 8, 9); but that further extension of the theorem to small areas is to be encouraged. Regarding the Schuster horizontal currents, von Bezold finds some resemblance between the magnetic and the meteorological diurnal variations, but sees a difficulty in the fact that Schuster's currents require one cyclone and one anticyclone in each hemisphere, while the conditions of solar radiation would give only one of each kind for the northern and the southern hemispheres combined.

Quite recently (1897) Dr. H. Fritsche has recomputed the Gaussian Constants to terms of the sixth order, depending upon the Neumayer Charts, 1885.0, beyond which development it is shown to be analytically disadvantageous to go. The outcome is a decided improvement in the representation of the distribution of the earth's magnetism for that epoch, but the question of the causes of the variations and the disturbances is not considered.

This brief summary of the latest investigations of the causes of the disturbances of the needle indicates that while the theory of atmospheric electric currents is the favorite one, yet the effort to employ it leads to uncertain and even contradictory conclusions. Having thus reviewed the status of the problem, we proceed to an exposition of the arguments in favor of the alternate hypothesis of the earth immersed in two external solar magnetic fields.

GENERAL NATURE OF THE PROBLEM.

In the papers[1] already published such considerations and conclusions have been reported regarding this solar-terrestrial problem as seemed justified by the developments secured. While indicating progress in

[1] Amer. Journ. Sci., Nov., 1890; July, 1891; Sept., 1891; Dec., 1894; Aug., 1895. Astron. and Astro. Phys., Feb., 1893; Oct., 1893; Nov., 1893; Jan., 1894. Astr. Soc. Pac., No. 14, 1891; No. 16, 1891. Amer. Metl. Journ., Jan., 1892; Sept., 1893; Jan., 1894; Jan., 1895. Smithsonian Instn. Monograph, Oct., 1889. Weather Bureau Bulletins, No. 2, 1892; No. 20, 1896. Science, Oct. 18, 1895; July 17, 1896.

the research, they were lacking in completeness for two reasons: First, because the bulkiness of the details of computation precluded a sufficient reproduction of the data upon which conclusions were based to satisfy the reader; and second, because the statements of subordinate parts could not be made in reference to the general result, since the final solution of the problem had not yet been attained. The difficulty of presenting the computation remains, but an effort will be made to furnish such specimens of it as will permit an accurate inference regarding the character of the data, especially in the critical parts of the work. This particularly applies to the period of the solar rotation, the discussion of the normal solar curve, the law of the inversion of the same, and origin of the great magnetic disturbances. It is likewise believed that a clear conception of the general problem in relation to its parts has been secured, so that the descriptions will be now more definite. The discovery of the phenomenon of inversion of the solar curve threw the research into confusion, and as long as a rational explanation of it was wanting, progress was naturally much impeded. This difficulty has, however, yielded and disclosed a law in harmony with the antecedent analysis, such that it not only confirms previous results, but furnishes a delicate test of the fact of the direct action of the sun as a magnet upon the earth.

The greatest obstacle in the way of conducting this research to a conclusion consists in the *looseness* that pervades the entire series of solar and terrestrial observations. This is not due to the instrumental inaccuracies, but inheres in the nature of the physical forces to be measured. The great distance of the earth from the sun of course reduces the magnetic force to a very small quantity; the variability of the solar output, including small abnormalities and great perturbations, serves to mask its normal field; the interaction of two magnetic fields, having regard to the aspects of the sun and the earth in their orbital revolution, introduces a curious system of effects on the instruments at our stations; the measurement of the transformed magnetic energy contained in the meteorological elements is seriously impeded by the strong convectional currents of the ordinary circulation of the atmosphere. In laying out the policy to be pursued in conducting the investigation it was decided to rely upon a very large exhibit of observations rather than upon any theory regarding them, and accordingly the entire mass of magnetic and meteorological data available has been examined for this purpose It has now become easy to perceive continuous symptoms of the action of the solar forces after having ascertained the laws that govern them, but a full verification of the work by others will involve an extensive use of the same observations.

In order to facilitate the description of the solution of the problem, a free allusion will be made to the following conclusions, which form the main features in the solar-terrestrial problem:

1. The sun emits two magnetic fields of force:

(1) The electro-magnetic, in radial vibrations.

(2) The polar, in curved lines of convergence.

2. These fields are each distorted in the neighborhood of the earth, as if it were a shell of permeable material, one-fifth the radius in thickness, placed in the paths of the undisturbed lines.

3. The force of the normal polar field of the sun is at the distance of the earth represented by a periodic curve, the synodic period being 26.68 days.

4. This normal type curve undergoes inversion in a semiannual period, and is a simple effect within the terrestrial magnetic field, due to the orbital aspects of the earth and the sun, as regards their magnetic lines.

5. The same typical normal curve exists in the atmospheric pressures and temperatures, especially of the west Canadian Provinces, together with the synchronous inversion.

6. The effect upon the general circulation of the currents of air is to facilitate the formation of highs and lows in a sequence prompted by the solar magnetic forces.

7. This leads to a theory of atmospheric circulation differing considerably from Ferrel's and from Hann's well-known views, but embodying the important facts of each, together with certain additional features.

SUMMARY OF THE RESULTS OF PREVIOUS RESEARCHES.

Current scientific opinion regarding the reach of the sun's magnetic field, if it exists, into space so far as to embrace the earth has unfortunately been molded into an attitude on the whole unfavorable to accepting the view just outlined. This impression, however, may properly be revised, in view of the great progress that has been made toward a fair understanding of the properties of the interstellar medium. Electromagnetic radiation requires an ether of enormous intrinsic potential power, and cosmical space is no longer to be conceived as filled with a thin or vacuous substance; matter is the product of the ether, rather than indifferent to it; to supplement these views, a polar system of magnetic force should now be added, having the sun as its seat of magnetization. Polarization, displacement, charge, number of lines of force per unit volume, are varying expressions for one fundamental property. The static and dynamic states have less need to stand over against each other as distinct ideas, just as potential and kinetic energy show a decided tendency to be merged into one; it is quite probable that dynamic concepts will finally absorb the static and potential, as merely limiting cases in the analysis. If it is proven that the sun sustains static polar magnetic lines, which are traversed by occasional transient, variable, currents, as well as the radiating shells of electro-magnetic energy, to the distance of the earth, then this must be an important factor in the final solution of the problems of the ether, and the nature of electricity and magnetism.

More especially, the objections to making the sun the seat of a field of polar magnetic force have been threefold, as stated above. (1) "If

the sun were a saturated steel magnet, end on to the earth and then reversed, the needle would be deflected only 10′ in arc." The substance of this argument has been repeated in many forms during the past fifty years. Admitting its truth, it does not exclude smaller deflections in the earth's magnetic field from being referred to such solar action. The indications are that certain variations of the needle depend upon a solar field, sustained by a magnetization usually less than saturated steel, and rising above it only temporarily, in great disturbances. (2) "Since an induced steel magnet loses its magnetization on increasing the temperature above a certain degree, the high temperature of the sun renders its own magnetization improbable." This argument proceeds on the assumption of an extrapolation of certain physical properties of matter, but it may or may not be true. It is offset by two leading facts: First, the earth is at high temperatures in the interior, far above the critical temperature of the steel in question, and yet it sustains a permanent magnetic field, so that a steel magnet is not the true analogue to the sun, but rather the earth itself. Second, a careful discussion of the curvatures of the lines visible at eclipses within the solar corona, shows that the system can be well accounted for by referring it to the equation of the lines of force surrounding a spherical magnet, the lines being seen in projection. (3) "The amount of work done in sending out the magnetic waves observed in great disturbances can not conceivably be attributed to any dynamical action within the sun." But if it is shown that certain moderate variations of the earth's field do come from external sources, by inference the sun, then in the account of the unusual disturbances, two courses are open: (1) By the discussion of the deflecting forces to prove that the energy does come from outside the earth, in accordance with which result the physical laws must be interpreted; (2) or else from the inside, in which case the causes of the perturbation of the earth's permanent magnetism must be investigated. The physical properties of the interior of the sun or the earth, as the case may be, can be studied as the results depending upon these deflecting forces indicate, but the whole subject being a mere question of fact, no hypothesis should form a barrier to an impartial investigation of the forces themselves, and all the consequences flowing from them. It may be concluded that it is "a perfectly proper object for investigation to find whether there is, or is not, any disturbance of terrestrial magnetism, such as might be produced by a [constant] magnet in the sun's place." (Kelvin, Nature, Vol. XLVII, p. 108.)

The positive testimony in favor of the direct magnetic action of the sun upon the earth is abundant, and on the whole powerful. It is summarized as follows: (1) The inclination and the intensity of the earth's magnetic field in all latitudes increases as the earth approaches the sun in its orbit; (2) all the magnetic elements undergo variation in the period of the solar rotation; (3) all the magnetic elements pass through secular variations in the 11-year period, synchronously with

the frequency of the sun spots, prominences, faculæ, and coronal extension; (4) the aurora, the earth currents, the atmospheric temperatures, pressures, the rainfall, the latitude of the mean storm tracks, the velocity of the eastward drift, suffer changes synchronous with the annual period, the solar rotation period, and the 11-year period; (5) the immediate connection between individual sun spots and terrestrial magnetic and atmospheric storms has not been clearly demonstrated, but there are several observations showing that abnormal agitations affect the sun and the earth as a whole and at the same time.

METHOD OF COMPUTING THE MAGNETIC OBSERVATIONS.

The study of the magnetic observations themselves involves the disentangling of the several periods, diurnal, solar rotation, annual, and 11-year. The first point to settle is the determination of what is to be taken as the earth's normal field, added to which the variations impressed at any given instant produce the actual field as observed. This involves the question of quiet days and large disturbances, in forming the monthly and annual means. My conclusion is as follows: (1) the so-called "quiet" day means merely that the trace is smooth—that is to say, not broken up with rough oscillations having wide amplitudes, but yet balanced on either side of a mean. This, however, is no criterion in itself whether the trace of a quiet day lies on the true secular normal of the element or not, and it is easy to see by inspection of the curves observed from day to day that a quiet trace is often depressed or elevated as a whole, relatively to the base line, compared with neighboring days, throughout its 24-hour extent. This swaying up and down of quiet traces throughout many millimeters seems to be fatal to the practice of taking the mean of quiet days by themselves as the true normal, inasmuch as many days of moderate oscillation are thus without reason excluded from the series of days upon which the mean depends. On the other hand the case is very different with the great disturbances, because these are not well balanced, but almost always show a large distortion, on one side of the mean of the element. Thus in the horizontal force the disturbances of pronounced type almost invariably diminish the absolute value of it for the 24-hour means. Hence, to include them in the normal would be to depress it to such an extent as to shift the mean on one side of its true position, and thus introduce a constant error into the system of deflecting forces. A comparatively wide oscillation of the component of the horizontal deflecting force σ amounts to about 0.000250 C. G. S., and this may occur without any unusual perturbation of the field. It is, on the other hand, equally erroneous to omit these disturbed days entirely from the mean, and I have compromised the matter by counting every disturbance above the limit just indicated as that value itself. Thus -0.000645 would be summed in the means as -0.000250. This is arbitrary, but it certainly saves an unnecessary distortion of the normal field. Hence

the rule becomes: "Diminish all disturbances to the limit 0.000250 and then take the mean of all the days of the month, this mean being the value of the normal field for the fifteenth day of the month; interpolate proportionally between the fifteenth days of successive months for the values of the normal on the several intermediate days; subtract the normal value for the day thus obtained from the observed value of the day, and the difference is the rectangular component in that element, horizontal force, declination, or vertical force ($\triangle H$, $\triangle D$, $\triangle V$), of the deflecting vector; reduce the number thus obtained to equivalent C. G. S., units (dx, dy, dz), and transform the same to the polar coordinates of the vector (σ, s, α, β); this is the vector of the deflecting force, impressed for the twenty-four hours upon the normal field at the station, to produce the observed force; s is the total vector acting in a plane having the azimuth β, counted N. W. S. E. from the magnetic meridian of the station; the vector is inclined at the angle α to the horizontal plane, and it is taken positive below σ, which is the component of s on the horizontal plane." In case the deflecting vector is required for a certain hour within the twenty-four hours composing the given day, the mean diurnal variation for that hour must be added to the interpolated normal mean, and this value for the hour is to be subtracted from the observed value to obtain the component of the element at that hour. In discussing disturbances it is necessary to take this step carefully, and not to omit it from the computation. In the course of the computations for the years 1878–1893, inclusive, I reduced 105 dates from some larger number to 0.000250 C. G. S.; half of them were small changes and the remainder large, thus making important changes in about *one per cent* of the dates. This method therefore makes use of all the given observations, except the extreme disturbances, in obtaining the mean value for the fifteenth day of each month, thus locating twelve points on the secular curve for the year, and assuming that the secular variations in the terrestrial elements progress uniformly from point to point. The method works well practically, and it seems to reduce the necessary assumptions to a minimum (Compare Bulletin No. 2, U. S. Weather Bureau, 1892, for details).

The vector systems of deflecting forces obtained in this way from the available published reports of magnetic observations, covering the years 1841 to 1895, inclusive, have been made the basis of the investigation. The labor consisted in making these simple transformations, but it is seen that no theoretical bias of any kind has been imposed upon the actual facts. The inferences obtained grow naturally out of the resulting systems of vectors of deflecting forces, after they are marshaled in array as determined by observations. For the greater part, this bulletin will be concerned with the vectors depending upon the 24-hour means, from which is to be derived the period of solar rotation and the characteristics of the solar magnetic field. This 24-hour vector system is evidently secured by confining the computation to the

columns "mean of 24 hours." If the hourly vectors are required, the work is limited to the "hourly means" for each month; if the hourly vectors for large disturbances are wanted, the two systems must be combined as mentioned above. All three of these processes have been executed with interesting results which it is proposed to enumerate, though the first will cover more ground than the others.

DIFFICULTY OF FINDING THE ROTATION PERIOD OF THE SUN.

Many attempts to find the true period of the solar rotation have been made by others, the investigations covering a half century, but the outcome is exceedingly unsatisfactory as regards a definite result. The attack has been made along three lines: (1) the rotation period of the sun spots, (2) the periodic variation of the terrestrial magnetic and meteorological elements, (3) the displacement of the lines in the solar spectrum. The outcome shows that the constituents of the sun have periods of rotation differing both in latitude and altitude, indicating some type of circulation not wholly unlike that of the currents in the earth's atmosphere. The law of the rotational periods in the several latitudes is quite easily and accurately determined where spots are visible, but the laws of extrapolation to latitudes outside the spot belts are not in agreement for the different authors.

TABLE I.—*Siderial and synodic periods of the rotation of the sun.*

[Compiled from Repertorium der Physik, p. 626, 1886, and other sources.]

Author.	From—	Siderial.	Synodic.
Faye	Carrington's observations	25.18	27.05
Spörer	Spörer's	24.55	26.32
Broun	Makerstown, 1844–45	24.20	25.92
Do	Greenwich, 1850–51–68–70	24.15	25.86
Hornstein	Prague, 1870	24.87	26.69
Do	Wien, 1870	24.61	26.39
Do	Inclination, Vienna, 1870	24.30	26.03
Do	St. Petersburg, 1870	24.48	26.24
Liznar	E. disturbances, Vienna, 1882–3	24.32	26.05
Do	W. disturbances, Vienna, 1882–3	24.24	25.96
Müller	All disturbances, Pawlowsk, 1882–3	24.03	25.66
Do	Horizontal intensity	24.09	25.79
Do	Vertical intensity	24.15	25.86
Do	W. disturbances in declination	24.16	25.87
Do	E. disturbances in declination	23.81	25.47
	Daily variation of barometer—		
Hornstein	Prag, 1870	24.12	25.82
Broun	Singapore, 1841–45	24.13	25.83
Bigelow	European magnetic field, 1878–1889	24.86	26.68
	Also extended, 1841–1897	24.86	26.68
Delambre	Sun spot observations	25.01	26.85
Spörer	do	25.23	27.10
Scheiner	do	25.33	27.22
Langier	do	25.34	27.23
Carrington	do	25.38	27.27
De la Landé	do	25.42	27.32
Cassini	do	25.58	27.51

TABLE I.—*Siderial and synodic periods of the rotation of the sun*—Continued.

ANGULAR ROTATION OF THE SUN SPOTS IN SEVERAL LATITUDES.

[Expressed in minutes of arc for the daily siderial motion.]

Latitude.	Carrington.	Spörer.	Faye.	Tisserand.	Bigelow.
	′	′	′	′	′
Equator	867	881	863	858	868.7
5°	864	862	....	....	....
9°	858	854	....	....	....
12°	854	*a* 852	....	....	....
14°	850	844	....	....	....
18°	842	833	....	....	....
21°	837	832	....	....	....
25°	830	827	....	....	....
30°	818	824	....	....	....

a Equivalent to 25.35 siderial, 27.24 synodic.

Table 1 shows the periods of rotation determined in several investigations and the mean daily motion of the spots in different latitudes. The mean synodic rotation of the total number of sun spots is 27.25 days, approximately, and it is the drift in solar mean latitude ± 12°. This value has been widely adopted as the period of solar rotation, but it is extremely difficult to see any reason why such an average motion, the mean of very different values in angular velocity, should be the true period of the solar nucleus itself. For sun-spot observations it may be useful, but certainly there is need of its further indorsement to make it applicable to the body of the sun as a whole. On the other hand, examination of the terrestrial data shows that there is a tendency to obtain periods lower than the mean number, 26.70 days, as the effective period of solar rotation at the distance of the earth. The separate determinations differ seriously among themselves, and tend to discredit one another, so that little weight has been given by astronomers to this set of results, perhaps less than they deserve. The spectroscopic work, though important, has not reached a conclusion, and can be regarded as only in its formative stage, though likely to produce decisive evidence in the end. As matters stand, the contest seems to have narrowed down to an assignment of 27.25 days or 26.70 days as the approximate period of synodic rotation of the sun, the former being the mean rotation of the spots in latitude ± 12°, and the latter that at the equator, as determined by the visible angular motion of the sun's surface and the terrestrial variations respectively.

It is proper to inquire why the terrestrial data should give such loose results. There are probably three reasons for this: (1) the observations give the data in a very complex form, composed of several interacting systems; (2) the series of observations used has been comparatively short, too brief to afford clear residuals after the wasteful process of balancing out local forces from other impressed sources of energy; (3) the employment of the Gaussian principle of the "sum of the squares of the residuals a minimum." The third needs further explanation. Having a series of residuals, the assignment of (n—1) (n)

(n+1) days as the period successively for the determination of n is proper under certain conditions, especially whenever a simple mean period is to be obtained—that is, for example, when the resulting curve is a simple harmonic function. But in the case of several overlapping functions it will not work, especially with a short series; and in case of an inversion of the periodic curve it will fail entirely. The fact that so many researches with this method have been indecisive induced me to believe that either one or both of these conditions were at the basis of the difficulty, and accordingly in planning this investigation the Gaussian method was excluded from the trial. The outcome shows that the inversion of the curve is the real cause of the failure of the method; the fact that the curve has many maxima in a period, but is not compounded of overlapping periods, not being the barrier to its employment. It will be shown later that inversion takes place on the average on February 1, April 20, July 15, October 15 of each year, so that unless the observations of a year were subdivided into the proper parts, the period would emerge only feebly from the observations.

NOMENCLATURE, DEFINITIONS, AND TYPE MAGNETIC FORCE DIAGRAMS.

For the sake of assisting those readers who are not familiar with the language used in the science of terrestrial magnetism, the following summary of its leading terms is reproduced from Bulletin No. 20, United States Weather Bureau, 1897, on Storms, Storm Tracks, and Weather Forecasting. The nomenclature grew up in consideration of the behavior of a magnet freely suspended in the earth's magnetic field, rather than with regard to the wider aspects of science that have since been developed, and hence the choice of reference directions on the surface of the earth is of a practical character, but not the best that might have been selected. Since the earth is positively magnetized in its southern hemisphere, in the northern hemisphere a freely suspended needle dips with its north-seeking end beneath the horizon, and inclines to the west of the geographical meridians, taken as a whole over Europe, where the science was first studied. This needle will hang tangent to the line of force determined by the earth as a magnet at the station considered, and there have consequently been employed two systems of coordinates to define the force of the magnetic field at the point of suspension.

(1) The first system of coordinates is—

F, the *intensity* of the magnetic force of the earth.

D, the *declination*, positive west from geographical north.

I, the *inclination*, positive below the horizon.

These give the exact direction and magnitude of the magnetic force.

(2) The secondary system of coordinates is—

H, the *horizontal component*, positive north along the magnetic meridian.

D, the *angular declination*, positive west.

V, the *vertical component*, positive downward.

These also determine the *vector*—that is, direction and magnitude—of the magnetic force.

If the earth's magnetic field were permanent, these values of F D I or H D V would be constant at every station on the globe. But they are all continually fluctuating in several periods—the diurnal, the solar, the annual, and the secular.

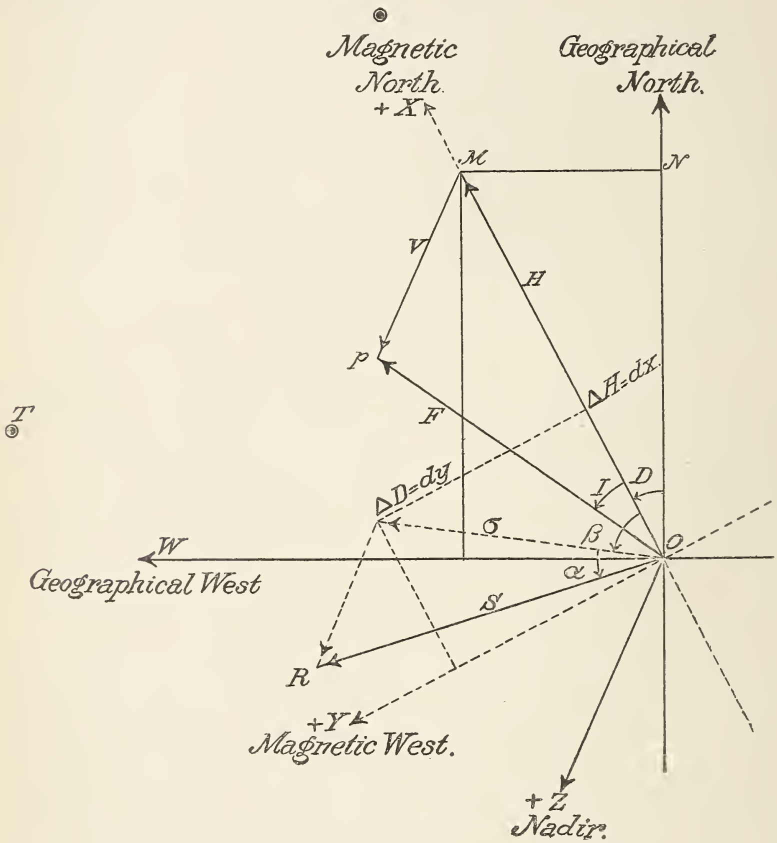


CHART 1.—Coordinates of normal and deflecting magnetic forces.

The *diurnal period*, twenty-four hours, is due to the rotation of the earth on its axis, changing the components of the earth's normal field in relation to the external magnetic lines of the force in the ether as induced by solar action.

The *solar period*, 26.68 days, is due to the rotation of the sun on its axis, carrying with it the *coronal* magnetic field, which it continuously sustains, with an intensity varying along the solar meridians, and also as a whole in the solar 11-year period.

The *annual period*, 365.25 days, is due to the earth's motion about the

sun in its orbit, which changes the aspect of the sun's magnetic system relatively to that of the earth, as the sun moves in declination with the seasons.

The *secular periods* are but little understood, but there are several of them: (1) The 11-year period, due to the slow workings of magnetic masses within the solar nucleus; (2) the longer periods of five hundred to three thousand years, differing in the several parts of the earth, and due to the slow redistribution of magnetism within the earth, and (3) the very long secular periods of the sun as a variable star by which the terrestrial system must be affected, just as it is in the shorter periods.

To study the causes that modify the earth's normal magnetic field in these several periods it is necessary to disentangle the superposed forces from the normal field, in order to have the components of the *deflecting forces* at any time. The simplest way of doing this in practical work is to take the magnetic meridian at a station as the plane of reference with—

X, positive to the magnetic north.

Y, positive to the magnetic west.

Z, positive to the magnetic nadir.

Hence, *variations* in the horizontal force $\triangle$ H, in the declination $\triangle$ D, in the vertical force $\triangle$ V, may be combined into a horizontal component σ, which makes an angle β on the horizon plane with the magnetic north, and also into a total vector force *s* which makes a vertical angle α with σ, and an angle β between its plane and that of the magnetic meridian. In Chart —

O N is geographically north, O W west, O Z nadir.

O P = F, N O M = D, M O P = I. First system.

O M = H, N O M = D, M P = V. Second system.

σ is the resultant of $\triangle$ H = dx and $\triangle$ D = dy, and makes the angle $\beta = \triangle$ H. O. $\triangle$ D with the magnetic meridian.

s is the resultant of σ and $\triangle$ V = dz and makes the angle $\sigma = \triangle$ D. O R with σ. The vector sum of O P and O R is O T, and therefore O T gives the direction of the needle and the intensity of the magnetic force at the time considered.

For many years it has been known that there must be a close physical connection between the sun and the earth because of the definite fluctuations in intensity between solar and terrestrial phenomena. Our investigation of this subject has shown that the transference of energy is not only along the ecliptic, but also in widespreading lines which are perpendicular to the ecliptic at the earth, this circumstance indicating that the sun, as well as the earth, is an immense spherical magnet. The sun therefore emits energy along two paths to the earth and in two different forms of radiation: (1) Along the ecliptic, in *electromagnetic* waves, wherein the vibration is in planes perpendicular to the line of propagation; (2) in *magnetic curves*, wherein the ether motion is prob

ably rotatory, which is called the *coronal* field because of the intimate relation of the lines of the solar corona to magnetic lines of force.

The term *electromagnetic*, in this connection, is descriptive of the Maxwellian theory of light, which makes it a true radiation of energy in straight lines from its source. It is analyzed into a wave of electric force, plus a wave of magnetic induction, these forces being at right angles to each other in the plane wave front, the component waves being in quadrature along the path of propagation. The immense rapidity of the vibrations of light, in the case of a train of waves from the source to the observer, practically integrates the system into a type of polarized ether.

The magnetic curves which join the opposite polarities of a permanent magnet have an entirely different nature, but it is not definitely known what the state of the ether is when it sustains them, though probably they are simply rotational ether vortices having their ends on the magetized matter. As the form of these curves, and the mode of combining systems of magnetic forces should be kept clearly in mind, the following diagrams are added:

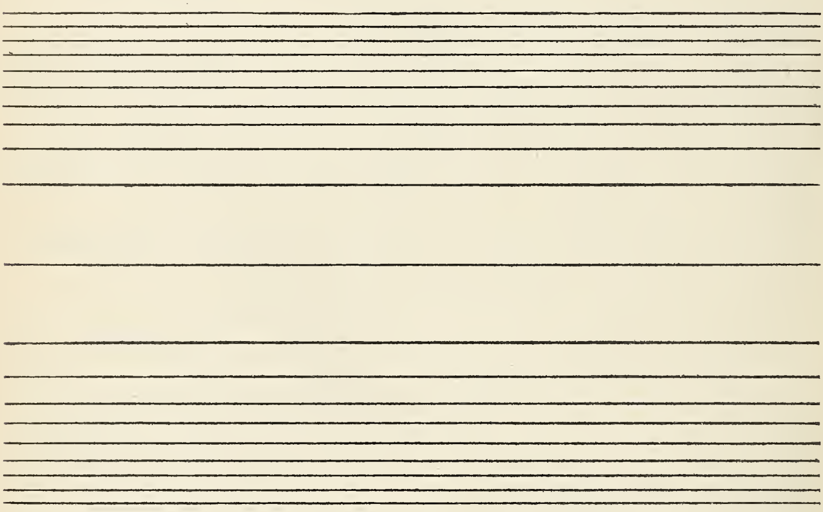


CHART 2.—Uniform field.

$$r_n = \sqrt{\frac{n}{\pi . H}} \qquad H = 0.001273 \frac{G^{\frac{1}{2}}}{C^{\frac{1}{2}} S}$$

With a given value of H compute the distance r_n from the axis of the field for any line n.

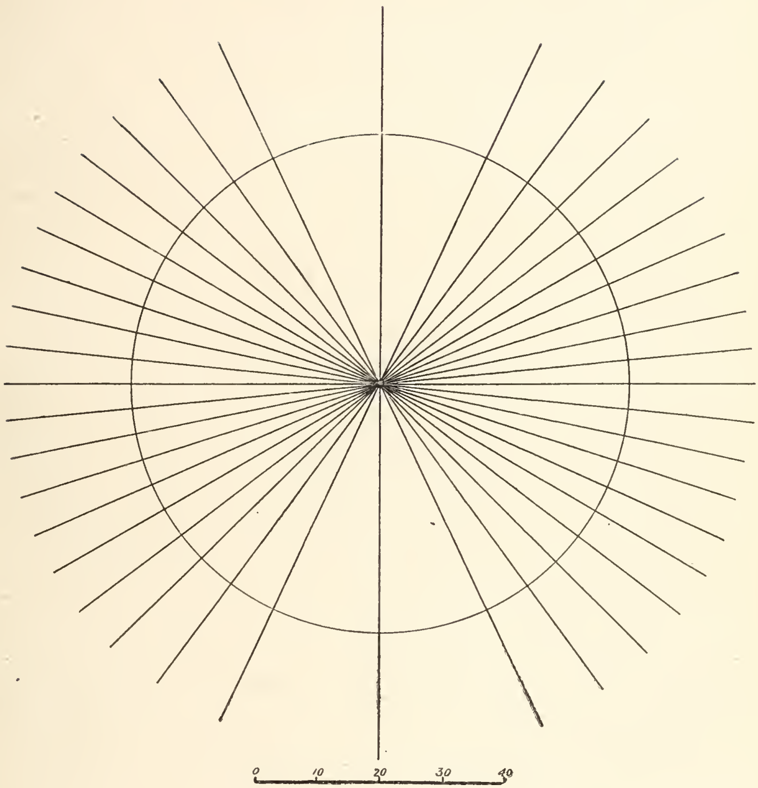


CHART 3.—Unipolar field.

$$F = 4\pi m = 20 \qquad m = 1.592\frac{C^{\frac{3}{2}}G^{\frac{1}{2}}}{S}$$

Subdivide the diameter into $4\pi m$ equal parts, draw parallel chords through the division points at right angles to the axis, and a series of radii to the points of intersection on the circle.

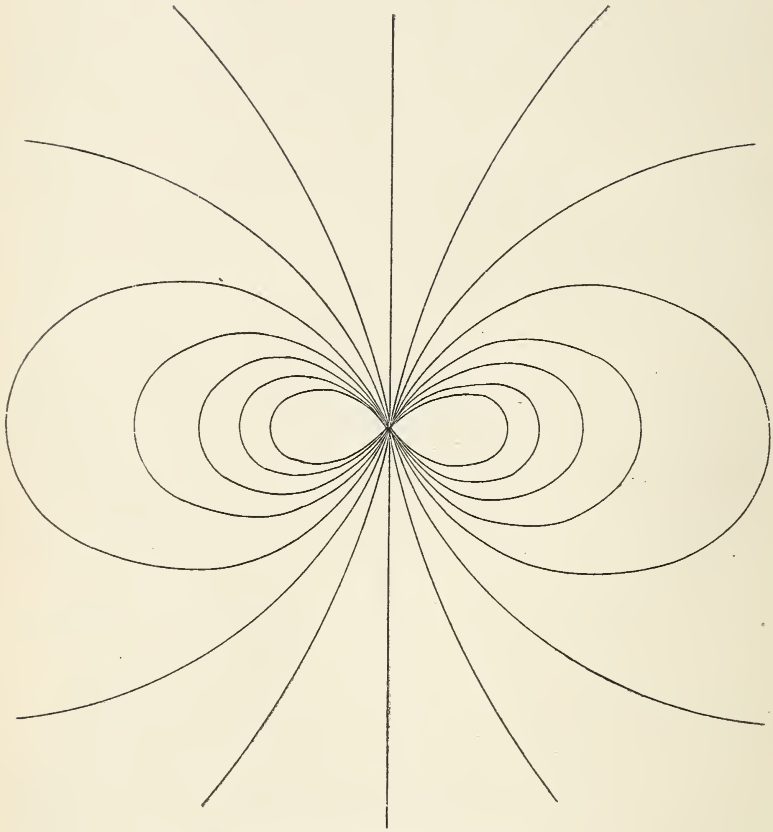


CHART 4.—Bipolar field or doublet.

$$\pm m = \pm 1.592 \frac{C^3 G^{\frac{1}{2}}}{S}$$

Place two unipolar fields near the same center and draw resultant curves through the points of intersection. Or else compute the curves from $N = C. \frac{\sin^2\theta}{r}$, where C may be taken equal to unity.

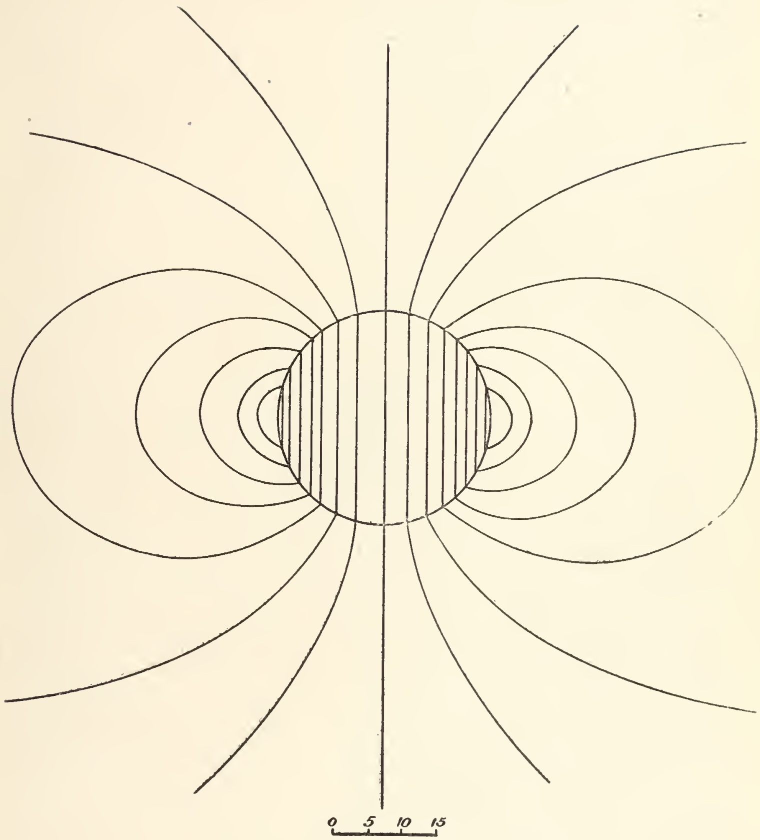


CHART 5.—Uniformly polarized sphere.

This is the same as a bipolar field outside the sphere, and a uniform field inside, connecting discontinuously at the surface.

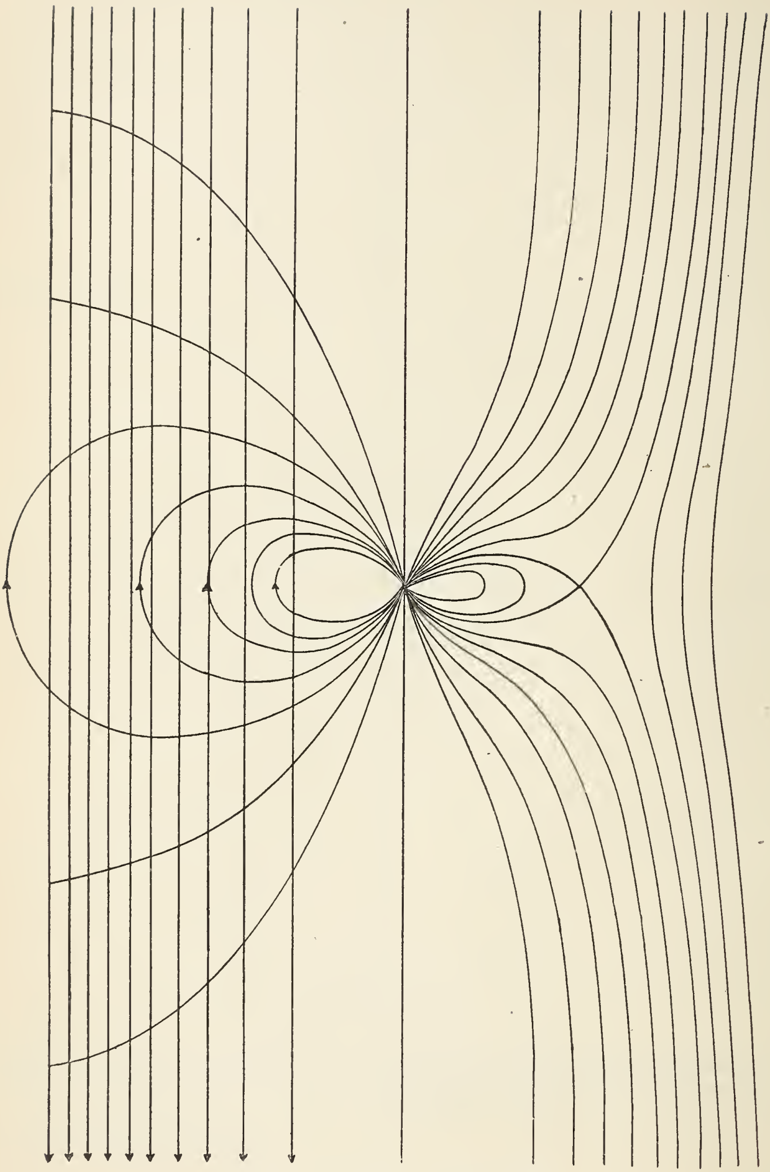


CHART 6.—Doublet in a uniform field.

Stable position. Components on the left side; resultant on the right side.

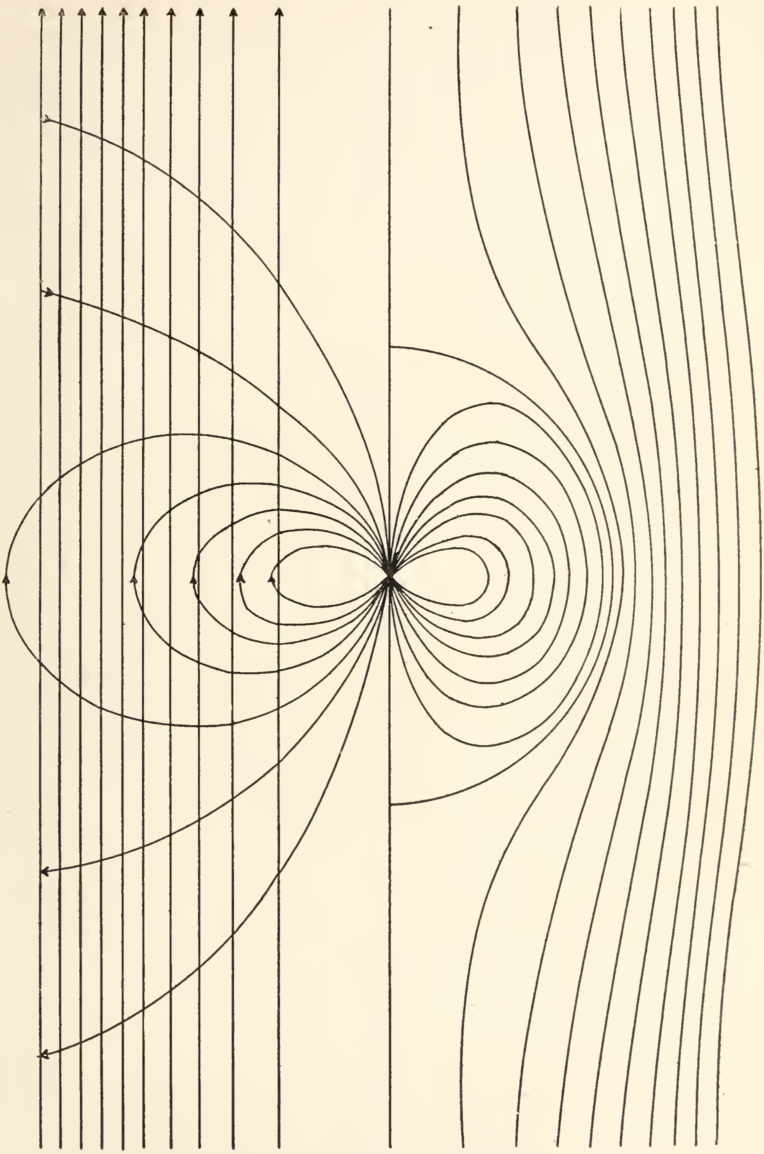


CHART 7.—Doublet in a uniform field.

Unstable position. Components on the left side; resultant on the right side.

The method of procedure decided upon was to spread out the polar coordinates of the deflecting forces impressed upon the normal terrestrial field, in long tables, and to discover by inspection the fact of periodicity if it existed. This has been a very laborious procedure, as the transformations above described cover the years 1878–1889 inclusive, for five to eleven stations. The result was announced at the Chicago Congress, 1893; but the possibility of having merely added one more to the long list of approximate periods already published, caused me to withhold the details of the computation till practical experience with its efficiency had given at least some conclusions calculated to fortify its validity. The work can be only illustrated in this bulletin, but the example given is a fair specimen of the remainder of this kind of computation.

The components are arranged in the order H. D. V., representing the development X. Y. Z.; H. D. V. are taken from the reports of observations, and are the absolute values corrected for temperature and instrumental peculiarities; H_0, D_0, V_0 are the adopted secular normal values of the components, assuming that the mean for the month is true for the 15th day, and that the variation is proportional to the time between the successive values thus determined; dx, dy, dz are the corresponding rectangular coordinates reduced to units of the sixth decimal C. G. S. (0.000001 dyne): $\sigma = \sqrt{x^2+y^2}$, $s = \sqrt{dx^2+dy^2+dz^2}$, $\tan\beta = \frac{dy}{dx}$, $\tan\alpha = \frac{dz}{\sigma}$; β is positive from the north magnetic point through the *west;* α is positive below the horizon.

In the volume of magnetical and meteorological observations, Greenwich, March, 1887, H is found in column 7, p. (iii); D in column 4, p. (ii); V in column 7, p. (vi); the precepts for conversion of the values into C. G. S. units occur at the top of the several pages.

$H - H_0 = \triangle H$, $D - D_0 = \triangle D$, $V - V_0 = \triangle V$,

1 unit $\triangle H = 0.0000018$ C. G. S.

1 unit $\triangle V = 0.0000044$ C. G. S.

1 minute arc $\triangle D = 0.0000530$ C. G. S., where $dy = H_0 \tan \triangle D$.

The table of transformations is appended; H. D. V. are copied from the report; H_0, D_0, V_0 are interpolated from the monthly means; $\triangle H$, $\triangle D$, $\triangle V$ are reduced to dx, dy, dz, in units sixth decimal C. G. S; σ, s, α, β are the equivalent polar coordinates.

TABLE 2.—*The mean deflecting forces in rectangular and polar coordinates.*

[Greenwich, March, 1887.]

	H	H_0	ΔH	D	D_0	ΔD	V	V_0	ΔV	dx	dy	dz	σ	s	a	β
					′	′										
1	464	477	−13	52.7	51.65	+1.05	497	483	+14	− 23	+56	+ 62	60	86	+46	112
2	477	477	0	52.2	51.65	+ .55	497	481	+16	0	+29	+ 70	29	76	+67	90
3	501	478	+23	52.0	51.65	+ .35	474	479	− 5	+ 41	+18	− 22	44	49	−26	25
4	499	478	+21	52.0	51.66	+ .34	478	476	+ 2	+ 38	+18	+ 9	42	43	+13	26
5	480	478	+ 2	51.7	51.66	+ .04	486	472	+14	+ 4	+ 2	+ 62	5	62	+86	27
6	418	479	−61	50.8	51.66	− .86	487	470	+17	−110	−46	+ 75	119	141	+32	203
7	429	479	−50	51.5	51.67	− .17	489	468	+21	− 90	− 9	+ 92	91	129	+45	186
8	431	480	−49	51.8	51.67	+ .13	479	465	+14	− 88	+ 7	+ 62	88	108	+35	174
9	401	480	−79	51.4	51.67	− .27	485	463	+22	−142	−14	+ 97	143	173	+34	185
10	469	480	−11	52.1	51.68	+ .42	462	461	+ 1	− 20	+22	+ 4	29	30	+10	133
11	450	481	−31	51.5	51.68	− .18	467	459	+ 8	− 56	−10	+ 35	57	68	+30	190
12	451	481	−30	51.8	51.69	+ .11	468	456	+12	− 54	+ 6	+ 53	55	77	+44	172
13	442	482	−40	51.6	51.69	− .09	469	454	+15	− 72	− 5	+ 66	72	97	+42	183
14	448	482	−34	52.2	51.70	+ .50	454	452	+ 2	− 61	+27	+ 9	67	68	+ 7	156
15	456	483	−27	51.7	51.70	.00	433	449	−16	− 49	0	− 70	49	86	−55	180
16	404	484	−80	51.2	51.67	− .47	437	448	−11	−144	−25	− 48	147	156	−18	190
17	458	485	−27	51.6	51.64	− .04	437	448	−11	− 49	− 2	− 48	49	69	−45	181
18	461	486	−25	51.5	51.61	− .11	423	447	−24	− 45	− 6	−106	46	116	−67	187
19	486	487	− 1	51.3	51.58	− .28	424	446	−22	− 2	−15	− 97	15	99	−81	268
20	463	489	−26	51.6	51.55	+ .05	418	446	−28	− 47	+ 3	−123	47	131	−69	176
21	407	490	−83	51.7	51.52	+ .18	425	445	−20	−149	+10	− 88	150	175	−30	176
22	467	491	−24	51.6	51.49	+ .11	402	444	−42	− 43	+ 6	−185	43	190	−77	172
23	527	492	+35	51.9	51.46	+ .44	400	444	−44	+ 63	+23	−194	67	204	−71	20
24	509	493	+16	51.8	51.43	+ .37	403	443	−40	+ 29	+20	−176	36	180	−78	35
25	552	495	+57	51.9	51.40	+ .50	416	442	−26	+103	+27	−114	106	155	−47	15
26	553	496	+57	51.6	51.37	+ .23	421	442	−21	+103	+12	− 92	104	139	−42	6
27	562	497	+65	51.5	51.34	+ .16	432	441	− 9	+117	+ 9	− 40	118	125	−19	4
28	555	498	+57	51.7	51.31	+ .39	440	440	0	+103	+21	0	105	105	0	12
29	577	499	+78	51.4	51.28	+ .12	433	440	− 7	+140	+ 6	− 31	140	143	−12	3
30	591	501	+90	51.5	51.25	+ .25	433	439	− 6	+162	+13	− 26	163	165	−19	4
31	585	502	+83	51.7	51.22	+ .48	442	438	+ 4	+149	+26	+ 18	152	153	+ 7	10
Feb.	471			51.6			517									
Mar.	483			51.7			449									
Apr.	521			50.7			428									

All the computations used as the basis of my research have been made in this way. About 1,500 tables like Table 2 have been constructed in preparing the results of this Bulletin. The great variety of forms in the publications of observatories, since scale divisions, British, metric, and C. G. S. units occur, renders the work tedious. An improvement would be made by publishing the coordinates (dx, dy, dz), and (σ, s, α, β) as above, since each observatory should contribute these as material available for general scientific work.

SOME REASONS FOR THE SLOW ADVANCEMENT OF THE SCIENCE OF TERRESTRIAL MAGNETISM.

This leads to a few remarks on the causes of the singularly slow advance that terrestrial magnetism has made as a science toward a satisfactory system of fundamental physical laws. For it is plain that while observations have been accumulated by the million, the primary laws of the sources of the variation of the forces are still the subject of discussion. This state of affairs may be referred to three lines of thought that have pervaded all previous analyses of magnetic observations: (1) The records have generally contented themselves with displaying the variations of the individual components taken separately. Thus the curves of Horizontal, Vertical, Total forces, Declination, and Dip occur in nearly every volume, but no attempt has been made on

a large scale to construct the corresponding vector system of impressed forces acting upon the entire earth, which will produce the same deflections in each element at each station. This has, on the other hand, been the leading idea of my computation, and out of it has emerged two definite vector systems, impressed upon the normal terrestrial field to produce the observed resultants.

(2) The prominence given to the potential, and the interpolation from station to station by the Gaussian Harmonic analysis, has probably tended to retard the elucidation of the origin of the variations of the field, because the excessive complication of the computation has really hindered the detection of the system of forces depending upon an external potential. It would seem preferable to disentangle the vector systems from each other, and from the normal field, then to study their behavior, and thus form a conception of the type of potential required. It is now seen that the interactions of the solar and the terrestrial magnetic fields well nigh overwhelm any simple potential action in the complex resultants, and thus obscure the solution of the problem.

(3) The common practice of subdividing the year by arbitrary calendar months, and taking the means for thirty-day blocks, evidently cuts to pieces any natural period which may happen to be running through the observations, but not coinciding exactly with the month divisions. This has been the natural course to pursue, however, so long as any such working period remained undetected, and hence the first logical step was to work out the periodic action within the observations, if such exists. At the outset, before any result could be found, it was necessary to employ the monthly means as representing approximately points on the normal field, and interpolating as explained. The discovery of the 26.68-day period, as the outcome of this method, enables us to construct an ephemeris dividing the total set of observations into periodic parts, and the means of these sets, instead of the thirty calendar days of the months, should be taken as the representative points of the normal field.

The repetition of the work thus implied has not been undertaken. When the laws of the secular variation of the normal field are known, a further improvement may be made in determining H., D., V., and hence a more accurate computation of the impressed vector systems. Enough has been done, however, to show that the apparently accidental variations in the daily means are really the effects of physical forces, attributed to the polar action of the sun, and not due primarily to instrumental defects. The observations are undoubtedly worthy of great confidence whenever the work has been carefully performed in the observatories.

DIAGRAMS GIVING SOME FEATURES OF THE COMPONENT MAGNETIC POLAR FIELDS.

Although it is anticipating the natural presentation of the results, yet in order to give an idea of the general conclusions reached, two

diagrams are added, which may be briefly described as follows: The earth acts like a permeable shell, one-fifth the radius in thickness, upon impressed external fields. Superposed upon the normal earth's field is a field nearly perpendicular to the plane of the ecliptic, deflected to pass the earth in the lines pertaining to such a system. If this field unites in composition with the terrestrial field, the curves of the earth's

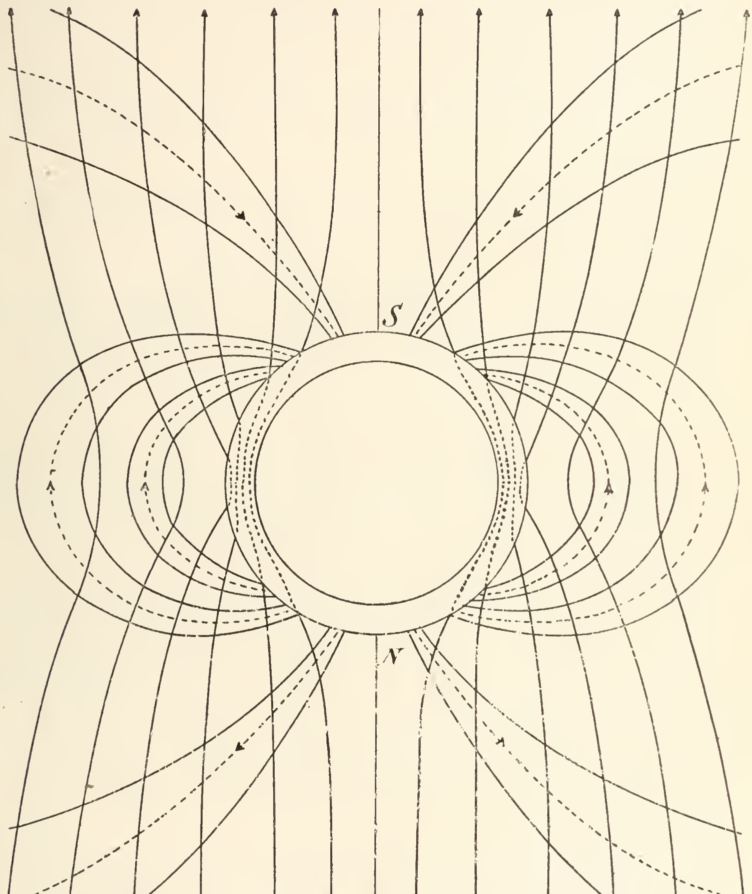


CHART 8.—Typical lines of the earth's field as deflected by the solar field.

field are expanded when it is directed from north to south, and contracted when its direction is from south to north. A variation in the strength of the external field for any cause is indicated by a change in the elements H. D. V. at the surface of the earth, and also throughout the space in its neighborhood.

The second diagram shows the resulting average variation of the

impressed field in a period of 26.68 days. It undergoes also a semi-annual periodic inversion as a whole, is subject to great perturbations, also to small abnormalities, and probably to minute wave-like variations which constitute it approximately a type of radiation. The earth's field is like a set of springs, which are deflected by the varying strength of the impressed field, itself primarily static in nature, but yet pulsating in long periods and in periods of a few seconds. The work of the transient currents of the impressed field goes one-half into magnetic energy and one-half into heat. The integral of the energy thus gained by the earth, and especially the earth's atmosphere, is apparently sufficient in quantity to modify the circulation of the currents of the air, due originally to the convection produced by solar radiation on the equatorial zone.

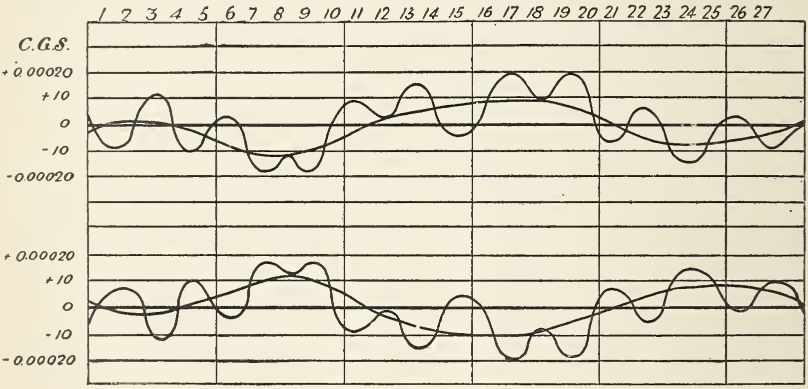


CHART 9.—Periodic variations in the strength of the solar field as observed within the earth's field. Direct and inverse types.

The axis of the earth's field is not parallel to that of the external field, but it rotates within it daily, around it annually; while also the sun rotates the external field past the earth as a whole in 26.68 days. The mechanical interaction of these systems constitutes the complexity of the problem, but it explains and renders necessary several well-known phenomena.

There is another impressed vector system, whose axis is parallel to the electro-magnetic radiation, the lines of which are distorted into a much more complicated form than those of the polar field, because the axis of the earth's magnetization, the earth having a permeable shell, is approximately at right angles to the equatorial field. This is the system observed in the diurnal variation of the needle. Thus two systems of forces are impressed from outside, one a static force, varying with the changes in its solar base; the other in intensely rapid vibration, generating a uniform field relatively to the mass of the earth or of a common magnet.

Chapter 2.

DETERMINATION OF THE 26.68-DAY SOLAR MAGNETIC PERIOD.

ELEMENTS OF COMPUTATION FOR 11 STATIONS, MARCH, 1887.

The form for computing σ, s, α, β for Greenwich, March, 1887, above described on page 41, is to be extended to all stations, whether the deflecting vectors are applied to the hourly or the mean daily variations of the normal terrestrial magnetic field. To show the relations simultaneously existing among these vectors at several stations of the northern hemisphere in the case of the mean variations for successive twenty-four hours, similar computations for Los Angeles, Toronto, Greenwich, Paris, Pola, Prague, Vienna, Pawlowsk, Tiflis, Zi-Ka-Wei, Batavia, are brought together for March, 1887. Those for Greenwich are transferred from the preceding Table 2. The preliminary Table 3, "Data from reports, with reduction factors to C. G. S. units," gives the name of the station, the values of H. D. V. for March, 1887, the factors needed to pass from the published data of the reports, $\triangle$H, $\triangle$D, $\triangle$V (in scale divisions, parts of the horizontal force, millimeters, minutes of arc), to the corresponding equivalents in the dx, dy, dz, sixth decimal C. G. S. units, and finally the pages of the reports from which the variations of the elements are extracted.

Table 3.—*Data from reports with reduction factors to C. G. S. units.*

[March, 1887.]

Station.	H.	D.	V.	Reduction factors to sixth decimal dyne.	References.
Los Angeles	0.27210	−14 28.0	....	H 1^{sc} = 0.000030 C. G. S. D 1^{sc} = 0.000063 C. G. S.	MSS.
Toronto	....	....	....	H 1^{sc} = 0.000109 C. G. S. D $1'$ = 0.000046 C. G. S.	MSS.
Greenwich	0.18148	+17 51.7	0.43705	H 1ΔH = 0.0000018 C. G. S. D $1'$ = 0.000053 C. G. S. V 1ΔV = 0.0000044 C. G. S.	II, III, VI.
Paris	0.19459	+15 56.0	0.42204	D $1'$ = 0.000057 C. G. S.	B, 18.
Pola	0.21913	+10 30.4	....	D $1'$ = 0.000064 C. G. S.	10, 11.
Prague	0.19641	+10 17.1	....	D $1'$ = 0.000057 C. G. S.	IX.
Vienna	0.20583	+ 9 22.4	0.41079	H 1^{mm} = 0.000042 C. G. S. D 1^{mm} = 0.000067 C. G. S. V 1^{mm} = 0.000062 C. G. S.	65, 77, 89.
Pawlowsk	0.16396	+ 0 25.6	0.46976	D $1'$ = 0.000048 C. G. S.	109, 121, 133.
Tiflis	0.25701	− 1 10.8	0.37614	D $1'$ = 0.000075 C. G. S.	15, 17, 19.
Zi-ka-wei	0.32970	+ 2 10.9	0.34433	D $1'$ = 0.000096 C. G. S.	37.
Batavia	0.37092	− 1 50.6	0.19992	D $1'$ = 0.000108 C. G. S.	104, 105, 106.

An emphatic protest may be entered, in passing, against continuing the publication of magnetic absolute values in so many systems, because the labor of comparative studies in terrestrial magnetism is seriously increased, and the danger of making an error in the interpretation of the data of reports is always menacing. It is also urged that each observatory should publish the values of the deflecting vectors in σ, s, α, β as being the really interesting product of the observations, thus sharing the labor of such computations. Only such reduction factors are entered as are needed in the transformations, the others being, as they should be, already in C. G. S. units. The vertical force was not available at the time this work was done for Los Angeles, Toronto, Pola, and Prague. The United States Coast and Geodetic Survey courteously furnished a manuscript advanced report for Los Angeles and the Toronto Meteorological Office for Toronto. To these offices our sincere thanks are extended.

TABLE 4.—*Polar coordinates of vectors disturbing the normal magnetic field at several stations for March, 1887.*

Day of the month.	Horizontal component σ. [Units sixth decimal C. G. S.]											Mean values for the European stations.	Total vector force s. [Units sixth decimal C. G. S.]							Mean values for the European stations.
	Los Angeles.	Toronto.	Greenwich.	Paris.	Pola.	Prague.	Vienna.	Pawlowsk.	Tiflis.	Zi-ka-wei.	Batavia.		Greenwich.	Paris.	Vienna.	Pawlowsk.	Tiflis.	Zi-ka-wei.	Batavia.	
1	40	20	60	51	37	119	47	48	11	25	43	43	86	87	84	52	69	288	86	80
2	68	71	29	68	60	138	41	18	27	54	39	37	76	82	89	28	38	224	90	63
3	104	77	44	84	97	191	92	71	112	11	79	81	49	90	133	72	115	298	126	92
4	111	101	42	80	87	237	90	71	124	99	129	81	43	80	129	71	127	179	159	90
5	71	84	5	52	60	....	2	15	47	68	171	24	62	67	102	37	53	79	175	164
6	118	72	119	82	91	....	117	137	117	135	32	114	141	93	118	138	128	210	81	124
7	37	8	91	21	46	....	108	41	111	147	66	74	129	62	110	80	126	191	84	101
8	95	97	88	42	23	....	110	83	51	87	26	75	108	48	117	112	52	220	27	87
9	45	94	143	100	85	....	164	147	147	217	111	140	173	110	164	149	177	240	123	155
10	45	43	29	43	7	....	58	47	14	148	47	38	30	45	59	49	40	232	130	45
11	32	37	57	27	39	140	90	54	38	110	33	53	68	30	90	61	42	139	89	58
12	27	3	55	21	31	90	65	21	27	119	15	38	77	22	69	40	31	224	19	48
13	34	24	72	49	41	109	25	28	34	25	27	42	97	92	45	9	55	73	52	60
14	73	27	67	60	135	101	26	41	51	70	19	49	68	81	27	41	55	147	63	54
15	6	38	49	81	56	105	38	39	59	93	49	53	86	96	42	43	60	95	74	65
16	49	45	147	81	89	117	99	113	54	66	68	99	156	93	105	120	55	66	81	106
17	56	50	49	31	31	102	28	15	12	85	91	27	69	108	30	18	12	153	120	47
18	106	52	46	43	48	69	57	22	50	134	36	44	116	78	57	26	51	268	41	66
19	131	78	15	84	72	27	113	89	60	173	34	72	99	89	113	91	61	334	41	91
20	71	10	47	47	57	33	83	42	83	252	92	60	131	51	91	42	84	258	130	80
21	36	66	150	68	58	141	40	28	90	48	44	75	175	79	58	30	103	179	50	89
22	31	53	43	52	57	78	7	24	56	126	18	36	190	80	47	26	128	148	40	44
23	158	130	67	6	36	26	8	27	3	97	35	22	204	78	26	38	110	120	48	91
24	83	128	36	87	71	76	57	58	68	56	97	61	180	89	78	88	68	81	102	101
25	40	11	106	26	26	65	25	51	39	91	14	49	155	61	63	53	89	107	21	84
26	3	6	104	3	40	66	37	28	40	100	53	42	139	73	67	37	132	326	75	90
27	43	40	118	14	35	42	53	24	13	45	34	44	125	73	83	34	120	396	77	87
28	49	27	105	20	22	9	50	24	24	78	33	45	105	64	87	34	205	202	92	99
29	69	35	140	61	111	14	94	12	30	31	43	67	143	63	94	13	121	224	92	87
30	130	40	163	80	133	50	104	73	90	72	60	102	165	80	107	80	168	159	92	120
31	135	83	152	130	....	111	101	111	134	88	103	126	153	130	112	114	190	133	121	140

TABLE 4.—*Polar coordinates of vectors disturbing the normal magnetic field at several stations for March, 1887*—Continued.

Day of the month.	Greenwich.	Paris.	Vienna.	Pawlowsk.	Tiflis.	Zi-ka-wei.	Batavia.	Mean values for the European stations.	Los Angeles.	Toronto.	Greenwich.	Paris.	Pola.	Prague.	Vienna.	Pawlowsk.	Tiflis.	Zi-ka-wei.	Batavia.	Mean geographical direction of vector.
	Vertical angle α [sign + is below horizon].								Azimuth angle β_1 [rotation from geographical north to west].											
1	+46	+54	−56	+26	+81	+85	−61	+30	309	343	130	29	61	6	57	21	66	247	58	N
2	+67	+34	−63	+48	+44	+76	−64	+26	345	233	108	9	20	7	32	40	328	180	349	N
3	−26	−19	−40	− 9	+13	+88	−51	−14	333	357	43	16	16	0	18	29	7	312	356	N
4	+13	− 4	−46	− 4	+12	+57	−36	− 6	10	6	44	18	26	7	26	44	17	15	347	N
5	+86	+37	−89	+64	+27	+30	−13	+ 5	69	32	45	349	8	....	29	43	9	350	354	N
6	+32	+28	−17	+ 8	+24	+50	+66	+15	113	139	221	244	236	....	215	233	221	180	220	S
7	+45	+70	−11	+59	+28	+39	+38	+38	102	185	204	261	229	....	191	219	192	175	135	S
8	+35	+27	−19	+43	+10	−66	−10	+19	147	178	192	142	258	....	194	208	194	189	314	S
9	+34	+25	+ 2	−10	+34	+26	−26	+17	146	144	203	179	204	....	191	192	195	185	179	S
10	+10	+12	+11	+14	+68	+50	−68	+23	166	173	151	359	55	....	181	164	206	187	98	S
11	+30	+26	− 3	+28	+21	−37	−68	+20	158	180	208	258	236	202	205	229	230	172	357	S
12	+44	+19	+18	+57	−27	−58	−35	+22	151	311	190	237	191	219	198	217	194	188	348	S
13	+42	−57	+56	+ 8	+51	+70	−58	+20	29	229	201	321	340	196	238	304	40	253	37	NS
14	+ 7	−42	+10	+ 2	+21	+62	−62	0	357	352	174	37	29	160	65	89	32	191	183	NS
15	−55	−32	+24	+28	− 9	+13	−48	− 9	146	222	198	205	54	133	21	58	29	197	247	NS
16	−18	−84	+19	−19	− 5	− 3	+33	−21	111	191	208	196	197	205	206	237	233	165	180	S
17	−45	−73	+17	+34	0	−56	+41	−13	22	237	199	356	90	162	53	91	39	191	194	NS
18	−67	−56	− 1	+24	− 6	+60	−28	−21	22	356	205	327	49	125	18	28	17	6	271	N
19	−81	−18	+ 2	+14	− 9	+58	−47	−18	3	353	286	354	0	102	1	357	15	8	340	N
20	−69	−21	−24	+ 2	−10	+12	−45	−24	59	185	194	11	33	255	5	334	334	359	354	N
21	−30	+31	−47	+23	−28	−74	+26	−10	136	148	194	215	172	160	201	219	211	4	184	S
22	−77	+49	+80	−18	−64	+31	−62	− 6	155	157	190	229	170	172	103	166	174	7	236	S
23	−71	+86	+71	−44	−88	+36	−42	− 9	189	152	38	235	166	268	126	240	317	19	348	S
24	−78	+10	+44	−49	− 4	+46	+17	−15	179	128	53	189	181	135	166	157	180	243	191	S
25	−47	+64	+67	+15	−64	−32	−46	+ 7	296	31	33	194	119	0	72	45	180	357	181	NS
26	−42	+87	+57	+40	−73	−72	+45	+14	120	150	24	328	62	44	48	53	359	14	21	N
27	−19	+78	+52	+43	−84	−84	+63	+14	314	336	22	97	107	12	28	75	35	178	286	N
28	0	+72	+54	+43	−83	−67	+69	+17	245	321	30	174	136	294	38	102	91	176	221	NS
29	−12	+17	+ 3	+16	−76	−82	+62	−10	327	31	21	15	4	96	11	65	52	201	32	N
30	−19	− 3	−13	−26	−58	−63	+49	− 5	329	348	22	16	11	45	15	28	14	327	342	N
31	+ 7	− 3	−27	−13	−46	−48	+33	−16	345	13	28	19	....	44	16	20	20	349	344	N

σ 61.6. s 85.7. $\cos\alpha$ 0.7188. α 44° 3′.

DISCUSSION OF THE RESULTS OF THE TABULATIONS.

An examination of the Table 4 of σ, s, α, β for eleven stations, March, 1887, two situated in North America, seven in Europe, and two in eastern Asia, thus embracing 180° or more in longitutude, shows that the magnetic action is simultaneous throughout the hemisphere. This is evident from the fact that the values of σ s tend to rise and fall together, in spite of many irregularities at the individual stations, whose exact cause may be referred partly to instrumental and partly to local conditions; also the values of the azimuth angle β_1 show a series of sudden reversals, as between March 5 and 6, March 20 and 21. Against each day is placed the letter N when the values of β_1 are in the large majority of instances directed northward, S when pointing southward, and NS when partly northward and partly southward, the field being then only irregularly disturbed from its normal state. The angle $\beta_1 = \beta +$ the magnetic declination of the station, and it gives the azimuth counted from the geographical north. This systematic reversal of the direction of the impressed deflecting forces over the entire northern hemisphere, extending also to the southern hemisphere at the same time, as can be readily demonstrated, is of prime importance in the solution of

our problem. It shows that only an extraterrestrial magnetic field can be primarily concerned in these variations of the earth's field taken as a whole from day to day, for the following reasons: If the variation is due to local changes in the earth's intensity of magnetization, it would not be simultaneous over both hemispheres; if it were due to changes in the magnetization within the earth taken as a whole, the variation in the external field would be that of vectors directed along the normal lines of force; if the disturbing vectors are not along the normal lines, but athwart them, as indicated in Chart 8, and the disturbance is simultaneous over the entire globe, it can happen only by the earth as a whole being immersed in an external field of greater or less strength than that contributing to the earth's normal field. If the earth's magnetization is constant and the earth is immersed in a uniform external field, then a normal steady field will surround the earth, compounded of these two; this is the observed normal H_0, D_0, V_0. When the external field varies, the $\triangle H, \triangle D, \triangle V$ thus arising show whence the cause of the variation resides. We do not need to laboriously compute potentials when the question is so immediately settled by the direction of the deflecting vectors, whether the disturbances of the normal field come from the outside or inside the earth.

VALUE OF THE ANGLE α FOR THE EUROPEAN FIELD.

Turning to α the altitude angle of the vector, it is seen that the irregularity in its values is very great and that this is the least useful of the elements. By comparing a large number of months, extending over several years, it is concluded that in the northern hemisphere positive values of α accompany southerly values of β; in a word, that the deflecting forces enter the northern hemisphere from north to south; they emerge in the southern hemisphere when directed southward (Chart 8). At each station on the average, the vector enters the earth at a constant angle; the field is therefore moved as if a component, forward or back, were exerted along a definite line, the amount of the give or take registering the strength of the external field.

To determine the values of the angle α, it is seen, by comparing the mean values of the horizontal component σ and the total vector force s for the same interval of time, that they stand in a nearly constant ratio to each other, $\sigma = s \cos \alpha$; this is persistent for a given station, from year to year. Confining the mean values in the case of March, 1887, to Greenwich, Paris, Vienna, Pawlowsk, Tiflis, in order to compare stations having about the same locality and having the same relation to the external field, we find the mean value of σ for March, 1887, 61.6; the mean value of s for March, 1887, 85.7, and hence $\cos \alpha = 0.7188$; $\alpha = 44° 3'$.

TABLE 5.—*Angle α for European stations, by periods.*

	1886.				1887.			
	σ	s	cos α	α	σ	s	cos α	α
				°				°
1	99	118	0.84	33	51	75	0.70	46
2	64	77	0.85	32	63	81	0.78	39
3	99	130	0.77	39	61	94	0.65	49
4	88	124	0.71	44	62	81	0.77	40
5	91	110	0.84	33	73	91	0.82	35
6	79	111	0.73	43	64	85	0.77	40
7	67	126	0.53	58	61	86	0.71	44
8	65	104	0.63	51	73	90	0.81	36
9	73	105	0.77	40	78	106	0.74	42
10	105	123	0.87	30	76	100	0.76	41
11	88	114	0.79	38	75	94	0.80	37
12	93	109	0.87	30	63	82	0.77	39
13	76	96	0.80	37	69	99	0.70	46
14	....	....	....	......	68	85	0.81	36

Mean α, 1886; 39° 5′; 1887, 40° 42′.

If the values of σ s are thus combined by the periods told off from the ephemeris soon to be constructed, 13 in 1886, and 14 in 1887, the individual values of α for each period are given in Table 5. The mean angle α for 1886 is 39° 5′, and for 1887, 40° 42′. For Europe generally it is about 40°, and this value persists for as many years as the angle has been followed in our computation.

VALUE OF THE ANGLE β_1 FOR THE EUROPEAN FIELD.

From the same tables the mean angle β_1 is about 7° west of north for Europe, as found by taking mean values of the angle. These angles, α β_1, determine the mean line along which the vector impinges upon the stations of Europe. Likewise the angles α β_1 have been determined for all available stations in both hemispheres. The result is that these vectors are impressed on the earth *nearly along the magnetic meridians, and as if radiating from the center of the auroral ovals*, being perpendicular to the isochasmen. (van Bemmelen, Meteorol. Zeit., Sept., 1895.); also that they touch the surface of the earth in the lines of the diagram No. 8, as if the earth were a shell of permeable magnetic material. These angles can be constructed with accuracy from the discussion of many observations. Since the vertical force is difficult to observe very accurately in regular observatory work, and the horizontal component is more steady and reliable, by the use of the mean angle α for a given station the horizontal variations can be made to check the results of the vertical-force instruments, and thus contribute substantially to their reliability.

It will be shown that an increase in the strength of the external field causes a diminution in the horizontal component and an increase in the vertical component over the entire earth and that these are equivalent to a vector pointing south and entering the earth in the northern but emerging in the southern hemisphere. This is evidently a proof positive that the earth is immersed in a variable magnetic field external to the earth and its atmosphere.

PERIODIC REVERSAL OF THE AZIMUTHS OF THE DEFLECTING FORCES DURING 1887.

Having shown the method of determining the vectors of the impressed forces at several stations, attention will be directed to the behavior of the geographical azimuth angle β_1 in the year 1887 for the same eleven stations. The March values are transferred to the proper place in Table 6 for 1887. All the rows are inspected and marked N or S, as described. It is readily perceived that the year tends to be subdivded into recurring groups, consisting of about twenty-seven days, and that each 27-day group is generally composed of a short part of about eight days and a long portion of nineteen days, on the average. Thus we have:

	Days.		Days.	Total days.
Jan. 5–Jan. 13	9 N	Jan. 14–Jan. 30	17 S	26
Jan. 31–Feb. 8	9 N	Feb. 9–Feb. 24	16 S	25
Feb. 25–Mar. 5	9 N	Mar. 6–Mar. 24	19 S	28
Mar. 25–Apr. 2	9 N	Apr. 3–Apr. 19	17 S	26
Apr. 20–Apr. 28	9 N	Apr. 29–May 17	19 S	28
May 18–May 23	6 N	May 24–June 12	20 S	26
June 13–June 20	8 N	June 21–July 6	16 S	24
July 7–July 14	8 S	July 15–Aug. 1	18 N	26
Aug. 2–Aug. 10	9 S	Aug. 11–Aug. 28	18 N	27
Aug. 29–Sept. 5	8 S	Sept. 6–Sept. 25	20 N	28
Sept. 26–Oct. 3	8 S	Oct. 4–Oct. 23	20 N	28
Oct. 24–Oct. 31	8 S	Nov. 1–Nov. 19	19 N	27
Nov. 20–Nov. 26	8 S	Nov. 27–Dec. 15	19 N	27
Dec. 16–Dec. 23	8 S	Dec. 24–Jan. 12	20 N	28
Means	8.30		18.40	26.70

Table 6.

JANUARY, 1887 (β_1).

Day.	Los Angeles.	Toronto.	Greenwich.	Paris.	Pola.	Prague.	Vienna.	Pawlowsk.	Tiflis.	Zi-Ka-Wei.	Batavia.	
1	327	185	204	29	42	359	351	151	332	251	349	N
2	348	236	226	161	....	9	1	29	306	318	348	N
3	56	211	280	81	....	351	191	167	338	328	349	NS
4	146	161	185	204	190	128	198	201	234	213	140	S
5	350	178	208	358	212	33	211	232	303	212	186	NS
6	337	359	150	41	76	15	53	32	359	344	345	N
7	356	297	69	34	21	22	27	29	7	330	352	N
8	342	0	41	39	10	32	17	357	358	343	357	N
9	341	356	61	34	10	72	18	31	1	356	351	N
10	329	349	44	21	14	34	19	27	7	359	5	N
11	335	19	58	36	20	54	40	37	18	342	341	N
12	333	358	350	32	348	355	46	14	356	352	351	N
13	329	337	45	35	23	46	29	34	11	354	343	N
14	150	166	198	203	352	98	28	351	9	355	10	NS
15	148	179	191	207	190	193	194	204	202	197	185	S
16	181	200	184	190	184	195	180	197	199	180	159	S
17	172	....	200	222	194	241	212	170	200	176	148	S
18	173	194	212	216	212	181	229	230	209	168	241	S
19	191	204	315	237	131	193	197	204	225	193	157	S
20	165	151	322	198	165	176	212	270	212	202	185	S
21	179	118	189	181	100	156	147	213	224	169	170	S
22	261	296	1	351	....	113	17	90	344	151	154	S
23	163	198	9	191	....	158	108	170	170	159	168	S
24	170	158	276	265	208	248	218	192	158	88	166	S
25	159	100	27	234	174	169	163	165	225	184	167	S
26	194	69	21	193	219	204	160	208	233	127	160	S
27	179	0	322	224	4	211	171	190	211	134	164	S
28	190	70	4	287	354	276	26	156	39	91	174	N
29	171	67	10	194	18	271	75	270	245	113	164	NS
30	215	47	22	22	191	270	216	138	223	91	162	NS
31	245	353	11	352	359	285	13	270	10	89	4	N

FEBRUARY, 1887 (β_1).

Day.	Los Angeles.	Toronto.	Greenwich.	Paris.	Pola.	Prague.	Vienna.	Pawlowsk.	Tiflis.	Zi-Ka-Wei.	Batavia.	
1	191	309	357	207	242	226	227	222	208	327	15	S
2	274	3	34	69	....	231	107	260	99	193	351	NS
3	196	4	353	1	....	306	11	346	13	303	359	N
4	341	14	8	42	126	341	2	44	15	10	346	N
5	189	26	2	105	210	299	251	244	268	347	356	N
6	317	13	31	41	142	309	20	90	37	182	305	N
7	317	346	60	54	80	25	55	90	33	270	349	N
8	324	186	62	31	24	16	30	61	39	286	332	N
9	171	186	184	292	10	250	246	287	4	352	2	NS
10	12	274	191	3	28	42	14	90	337	216	342	N
11	357	184	191	36	45	60	16	8	340	346	52	N
12	158	181	211	222	208	202	218	197	195	244	142	S
13	167	208	215	298	208	238	211	229	201	195	181	S
14	152	178	210	244	211	226	231	203	207	180	205	S
15	191	211	204	198	214	209	194	218	183	177	193	S
16	212	140	204	202	89	223	203	181	198	189	201	S
17	100	166	203	183	....	297	8	355	339	188	208	NS
18	355	193	270	352	....	272	354	359	338	238	334	N
19	196	185	356	22	....	160	11	310	322	1	355	N
20	237	86	199	167	179	143	160	211	202	359	126	S
21	117	198	102	177	171	136	191	176	193	133	150	S
22	137	136	97	157	152	104	101	177	205	32	200	S
23	160	175	12	196	192	211	182	217	209	354	197	S
24	176	20	16	166	215	27	179	91	154	17	186	S
25	332	17	15	67	83	26	31	33	29	20	182	N
26	56	335	16	66	282	11	23	39	48	1	162	N
27	317	152	84	113	138	21	180	300	242	2	181	N
28	5	342	24	106	66	13	37	51	22	25	199	N

TABLE 6—Continued.

MARCH, 1887 (β_1).

Day.	Los Angeles.	Toronto.	Greenwich.	Paris.	Pola.	Prague.	Vienna.	Pawlowsk.	Tiflis.	Zi-Ka-Wei.	Batavia.	
1	309	343	130	29	61	6	57	21	66	247	58	N
2	345	23	108	9	20	7	32	40	338	180	349	N
3	333	357	43	16	16	0	18	29	7	312	356	N
4	10	6	44	18	26	7	26	44	17	15	347	N
5	69	32	45	349	8	....	29	43	9	350	354	N
6	113	139	221	244	236	....	215	233	221	180	220	S
7	102	185	204	261	229	....	191	219	192	175	135	S
8	147	178	192	142	258	....	194	208	194	189	314	S
9	146	144	203	179	204	....	191	192	195	185	179	S
10	166	173	151	359	55	....	181	164	206	187	98	S
11	158	180	208	258	236	202	205	229	230	172	357	S
12	151	311	190	237	191	219	198	217	194	188	348	S
13	29	229	201	321	340	196	238	304	40	253	37	NS
14	357	352	174	37	29	160	65	89	32	191	183	NS
15	146	222	198	205	54	133	21	58	29	197	247	S
16	111	191	208	196	197	205	206	237	233	165	180	S
17	22	237	199	356	90	162	53	91	39	191	194	S
18	22	356	205	327	49	125	18	28	17	6	271	N
19	3	353	286	354	0	102	1	357	15	8	340	N
20	59	185	194	11	33	255	5	334	334	359	354	N
21	136	148	194	215	172	160	201	219	211	4	184	S
22	155	157	190	229	170	172	103	166	174	7	236	S
23	189	152	38	235	166	268	126	240	317	19	348	S
24	179	128	53	189	181	135	166	157	180	243	191	S
25	296	31	33	194	119	0	72	45	180	357	181	NS
26	120	150	24	328	62	44	48	53	359	14	21	N
27	314	336	22	97	107	12	28	75	35	178	286	N
28	245	321	30	174	136	294	38	102	91	176	221	NS
29	327	31	21	15	4	96	11	65	52	201	32	N
30	338	348	22	16	11	45	15	28	14	327	342	N
31	345	13	28	19	....	44	16	20	20	349	344	N

APRIL, 1887 (β_1).

Day.	Los Angeles.	Toronto.	Greenwich.	Paris.	Pola.	Prague.	Vienna.	Pawlowsk.	Tiflis.	Zi-Ka-Wei.	Batavia.	
1	333	347	26	18	....	43	19	21	12	356	4	N
2	307	315	59	304	308	2	329	0	353	359	32	N
3	341	80	99	171	187	71	155	309	275	7	0	NS
4	146	129	352	297	....	89	338	332	5	1	10	N
5	166	193	211	214	....	195	201	232	195	41	162	S
6	176	196	184	174	184	180	162	201	181	77	178	S
7	166	214	190	191	197	212	189	193	174	166	183	S
8	165	177	221	226	208	234	207	197	148	132	165	S
9	146	196	190	203	186	224	180	192	182	149	159	S
10	156	183	158	193	196	164	186	212	174	167	181	S
11	181	191	132	174	165	140	165	132	155	179	165	S
12	167	117	308	330	232	120	213	189	190	156	166	S
13	101	11	40	23	123	61	135	342	281	186	181	NS
14	315	313	35	34	26	50	34	27	35	179	322	N
15	95	275	162	177	158	119	170	207	214	186	230	S
16	30	354	345	308	19	220	17	1	20	196	6	N
17	30	93	170	144	95	170	120	7	190	187	122	S
18	25	350	179	147	43	78	98	130	43	199	171	NS
19	1	8	196	19	25	1	14	9	25	269	345	N
20	353	21	326	24	20	19	5	348	346	248	344	N
21	346	24	175	72	49	34	38	95	60	241	332	N
22	331	356	344	355	3	355	351	19	12	350	27	N
23	252	186	281	19	336	341	260	293	22	2	358	N
24	336	5	322	2	358	201	351	102	141	42	152	N
25	242	112	132	113	136	98	153	139	179	282	118	S
26	330	22	359	44	11	330	62	28	61	257	154	N
27	342	19	8	26	14	341	18	17	20	1	359	N
28	120	158	334	344	348	3	334	333	320	357	9	N
29	187	174	223	184	206	152	185	184	192	186	183	S
30	0	194	285	224	347	335	184	130	169	178	162	S

Table 6—Continued.

MAY, 1887 (β_1).

Day.	Los Angeles.	Toronto.	Greenwich.	Paris.	Pola.	Prague.	Vienna.	Pawlowsk.	Tiflis.	Zi-Ka-Wei.	Batavia.	
1	**243**	**114**	**232**	**217**	**238**	316	**233**	**233**	318	355	**116**	S
2	**202**	**209**	338	44	303	292	71	**133**	324	**260**	**175**	N
3	**153**	**167**	294	**195**	**203**	**167**	**195**	**219**	308	80	**190**	S
4	**171**	**144**	329	**216**	**207**	**241**	**194**	**188**	312	311	**186**	S
5	**148**	**161**	318	271	**204**	**224**	**207**	**174**	**123**	320	**215**	S
6	**171**	**183**	9	**241**	**187**	**226**	**165**	10	**264**	**190**	**183**	S
7	**140**	61	323	**205**	**202**	**234**	**191**	**210**	**236**	**192**	**247**	S
8	352	61	59	**240**	**170**	**194**	**164**	78	30	**188**	6	NS
9	326	70	38	43	**176**	3	93	331	4	**183**	336	N
10	279	57	46	25	**166**	41	65	46	16	1	4	N
11	324	3	66	41	**100**	58	82	**115**	26	17	358	N
12	344	347	26	19	26	31	21	24	11	359	5	N
13	30	50	33	343	357	87	10	89	74	356	**178**	N
14	**189**	**146**	**126**	65	**143**	86	61	57	**222**	357	**120**	NS
15	75	**202**	**161**	75	**168**	**143**	**188**	**175**	**161**	6	**204**	S
16	86	321	**173**	345	**189**	**168**	**203**	**181**	**178**	347	56	S
17	**161**	332	**159**	83	**187**	**239**	**199**	**244**	84	336	342	S
18	**218**	305	**154**	22	24	**160**	4	352	**176**	6	**135**	S
19	**168**	22	40	16	13	332	37	60	**174**	16	318	N
20	25	41	**203**	**206**	**209**	**261**	**195**	**202**	**159**	44	**170**	S
21	6	12	**204**	355	1	340	354	354	1	**243**	5	N
22	301	84	**199**	67	18	18	356	319	330	276	11	N
23	8	303	340	35	29	34	20	42	32	32	4	N
24	303	**201**	**195**	**188**	**197**	**136**	**195**	**195**	351	**185**	**186**	S
25	**122**	**168**	**192**	**181**	**186**	**165**	**190**	**203**	10	**186**	**181**	S
26	46	67	308	**188**	**211**	**150**	**221**	**252**	**194**	**152**	**162**	S
27	**127**	73	304	**238**	**252**	288	**248**	317	**172**	....	353	NS
28	**157**	**207**	357	**168**	**199**	**181**	**190**	**182**	**182**	....	**191**	S
29	**171**	**194**	322	**191**	**100**	6	**113**	64	**179**	340	329	S
30	41	300	327	305	....	292	**215**	23	**154**	232	**170**	N
31	23	18	....	308	....	337	312	**161**	**159**	**156**	**175**	NS

JUNE, 1887 (β_1).

Day.	Los Angeles.	Toronto.	Greenwich.	Paris.	Pola.	Prague.	Vienna.	Pawlowsk.	Tiflis.	Zi-Ka-Wei.	Batavia.	
1	**232**	**149**	....	344	324	299	**180**	299	321	**176**	345	N
2	5	52	....	274	314	**241**	**205**	**264**	**253**	**173**	8	S
3	342	53	6	**267**	352	283	354	**190**	5	**194**	356	N
4	324	19	24	14	8	302	10	7	355	303	353	N
5	**152**	**152**	**180**	**179**	**171**	**218**	**186**	74	**194**	**200**	**201**	S
6	7	358	**187**	**250**	305	**256**	**209**	**192**	**202**	**155**	**169**	S
7	32	51	**172**	**121**	**100**	**231**	**165**	**195**	56	348	322	NS
8	334	306	32	18	36	316	31	47	43	83	43	N
9	332	277	338	340	334	273	28	334	16	**168**	14	N
10	300	**96**	**142**	**101**	**166**	**259**	**222**	**134**	**160**	**198**	**179**	S
11	**286**	359	**168**	33	24	**220**	**112**	85	**95**	9	33	NS
12	273	313	**191**	18	280	**230**	**185**	**236**	**108**	11	10	NS
13	**170**	**198**	**205**	**203**	**192**	**195**	**184**	35	**181**	**232**	**195**	S
14	63	**264**	**188**	**179**	**194**	**227**	**195**	**221**	**208**	**179**	**175**	S
15	**151**	43	284	**197**	**216**	**257**	**202**	**224**	**217**	**186**	**175**	S
16	**155**	16	3	48	**199**	**253**	**167**	**232**	**240**	**206**	**209**	S
17	44	33	344	336	306	285	309	326	294	93	322	N
18	349	337	23	26	23	25	21	34	337	7	18	N
19	291	331	35	51	55	**103**	32	25	327	350	237	N
20	43	217	**234**	307	17	54	311	**184**	35	13	**174**	N
21	**202**	**262**	**179**	**217**	**152**	86	**219**	**147**	**156**	0	**171**	S
22	**191**	**157**	**209**	**233**	**212**	**140**	**226**	**247**	**194**	11	**171**	S
23	**203**	**156**	**202**	286	**187**	**152**	282	**239**	**202**	356	**168**	S
24	**161**	**149**	**190**	**176**	**155**	**124**	353	**171**	**168**	....	**181**	S
25	**210**	**96**	**188**	**135**	**170**	**118**	**165**	337	**192**	**187**	**200**	S
26	277	29	278	288	343	36	35	**103**	69	**235**	**200**	N
27	**233**	30	**167**	**164**	28	74	**121**	**137**	**133**	326	**225**	NS
28	**253**	4	**185**	302	340	71	76	**232**	299	354	**173**	N
29	347	359	81	28	19	41	39	43	19	0	**190**	N
30	322	11	**155**	33	12	43	23	358	5	357	298	N

Table 6—Continued.

JULY, 1887 (β_1).

Day.	Los Angeles.	Toronto.	Greenwich.	Paris.	Pola.	Prague.	Vienna.	Pawlowsk.	Tiflis.	Zi-Ka-Wei.	Batavia.	
1	263	35	162	107	29	54	209	105	146	9	5	N
2	237	349	146	16	14	5	251	318	186	1	356	N
3	266	11	169	123	48	13	261	293	359	6	12	N
4	317	95	67	35	28	25	14	17	15	8	0	N
5	311	36	49	18	16	7	10	24	16	2	4	N
6	151	144	172	198	237	131	230	354	253	4	21	S
7	148	208	189	199	....	152	194	183	184	166	176	S
8	162	209	193	192	191	142	205	193	190	100	180	S
9	219	176	195	211	206	171	202	201	192	168	180	S
10	153	195	156	72	227	116	211	230	216	177	348	S
11	138	200	180	200	234	187	204	244	195	177	251	S
12	128	184	175	180	153	185	182	188	190	179	182	S
13	163	219	190	198	210	202	191	216	188	184	191	S
14	28	95	287	260	277	240	228	206	215	180	171	S
15	32	298	15	63	168	230	42	36	48	182	14	N
16	36	35	10	202	11	230	18	135	67	184	205	NS
17	7	117	248	301	238	244	270	233	252	187	196	S
18	4	20	307	294	315	297	237	348	1	189	348	N
19	90	301	228	305	42	180	57	9	322	180	303	N
20	137	284	0	344	278	311	280	280	232	179	211	N
21	13	69	196	314	210	226	221	277	186	188	161	S
22	353	42	335	1	85	17	47	6	62	204	100	N
23	46	3	16	15	18	353	....	348	338	208	41	N
24	21	15	90	26	137	67	....	25	58	219	110	N
25	28	20	59	23	106	39	35	356	32	221	21	N
26	336	33	36	5	78	322	8	61	53	295	343	N
27	329	350	22	30	60	350	18	16	12	348	17	N
28	355	12	336	359	70	355	14	348	328	2	2	N
29	349	1	4	10	30	303	17	18	20	347	24	N
30	351	4	346	23	43	350	29	16	31	5	19	N
31	356	10	352	21	34	331	26	3	5	349	7	N

AUGUST, 1887 (β_1).

Day.	Los Angeles.	Toronto.	Greenwich.	Paris.	Pola.	Prague.	Vienna.	Pawlowsk.	Tiflis.	Zi-Ka-Wei.	Batavia.	
1	179	232	11	18	8	283	21	8	9	359	352	N
2	176	212	261	218	223	191	198	187	189	155	182	S
3	171	187	144	151	194	171	182	216	202	137	174	S
4	161	167	204	186	194	176	189	235	194	172	175	S
5	176	178	158	134	117	162	131	124	172	180	182	S
6	174	106	228	226	193	179	204	209	192	188	206	S
7	167	163	217	237	171	194	207	204	202	181	185	S
8	157	201	206	237	172	189	195	200	183	172	196	S
9	19	36	257	307	244	174	230	250	278	347	325	S
10	339	47	184	345	224	142	273	258	341	174	350	NS
11	13	28	160	16	208	131	274	294	325	193	351	NS
12	349	1	191	9	328	120	312	231	344	174	359	N
13	344	354	110	35	24	77	13	13	3	6	7	N
14	344	294	173	9	9	71	359	17	2	27	345	N
15	212	339	206	320	267	197	278	279	330	4	226	NS
16	36	171	155	57	79	98	119	144	218	184	172	S
17	7	324	117	73	43	34	88	20	12	197	346	N
18	347	341	83	65	38	128	38	4	338	211	348	N
19	341	45	191	337	30	149	38	42	33	154	4	N
20	1	23	104	53	31	24	27	30	19	25	350	N
21	22	9	173	16	2	11	1	11	7	353	351	N
22	327	13	188	192	154	15	178	356	60	352	348	NS
23	330	357	179	168	79	2	15	343	5	19	13	N
24	359	13	123	17	43	7	21	43	69	9	357	N
25	321	352	42	18	32	12	15	17	17	0	3	N
26	359	11	26	1	39	11	12	12	16	350	345	N
27	8	9	13	346	12	357	354	5	24	29	337	N
28	342	165	4	288	266	333	291	321	349	5	338	N
29	189	187	16	196	203	341	234	207	197	155	191	S
30	188	182	36	199	173	256	182	184	182	164	176	S
31	223	177	16	255	57	332	186	102	176	161	176	S

Table 6—Continued.

SEPTEMBER, 1887 (β_1).

Day.	Los Angeles.	Toronto.	Greenwich.	Paris.	Pola.	Prague.	Vienna.	Pawlowsk.	Tiflis.	Zi-Ka-Wai.	Batavia.	
1	220	158	34	182	176	....	176	160	184	195	186	S
2	177	169	23	189	180	....	181	185	188	260	182	S
3	164	165	313	194	171	....	183	196	177	348	153	S
4	198	169	9	198	162	....	172	139	170	0	96	S
5	303	6	12	152	161	....	169	150	166	7	11	S
6	321	343	20	76	148	....	177	196	186	21	357	N
7	332	322	12	7	58	....	25	17	355	317	11	N
8	349	346	10	5	....	....	16	27	8	173	6	N
9	2	357	21	15	....	....	21	27	13	207	2	N
10	351	301	20	14	....	....	33	52	20	179	25	N
11	75	303	299	320	....	....	333	357	15	190	10	N
12	6	2	256	258	....	....	247	330	3	168	359	NS
13	359	14	209	312	....	....	3	65	4	199	344	N
14	341	236	23	24	....	....	18	26	16	357	0	N
15	197	233	148	26	87	....	351	324	358	356	350	N
16	297	19	133	60	96	....	59	97	159	225	196	S
17	324	1	10	354	111	....	343	45	31	93	320	N
18	321	357	31	44	106	....	292	28	13	93	359	N
19	352	11	40	24	80	....	21	13	9	4	356	N
20	344	356	47	4	65	....	32	17	5	10	45	N
21	325	1	41	32	....	....	34	43	19	166	14	N
22	344	306	104	62	....	....	64	84	45	93	350	N
23	74	42	263	308	....	....	342	294	353	6	6	N
24	20	349	211	87	....	....	351	226	212	357	192	NS
25	171	182	....	270	....	....	289	280	309	3	5	N
26	174	169	....	188	....	....	193	196	190	176	190	S
27	173	175	210	202	....	....	220	198	186	183	175	S
28	176	167	194	185	....	....	188	192	185	157	180	S
29	111	195	201	201	....	....	194	206	201	0	183	S
30	110	99	204	205	....	....	198	196	179	357	177	S

OCTOBER, 1887 (β_1).

Day.	Los Angeles.	Toronto.	Greenwich.	Paris.	Pola.	Prague.	Vienna.	Pawlowsk.	Tiflis.	Zi-Ka-Wai.	Batavia.	
1	116	179	142	194	....	....	189	202	179	175	111	S
2	151	176	151	195	....	....	189	178	190	184	313	S
3	25	201	47	199	....	....	192	217	204	186	348	S
4	9	185	35	174	....	....	165	175	14	187	352	NS
5	327	335	34	44	....	....	83	38	15	218	353	N
6	285	140	56	27	....	....	138	35	17	273	357	N
7	346	322	23	339	....	....	135	11	10	186	32	N
8	11	14	79	90	....	....	196	5	2	273	349	N
9	342	33	50	21	225	....	233	348	343	199	335	N
10	325	275	44	27	9	....	44	334	5	204	351	N
11	334	329	153	327	338	....	324	4	338	196	357	N
12	175	236	179	261	....	....	323	305	2	190	216	S
13	138	167	190	217	....	....	213	124	232	172	172	S
14	120	169	198	221	11	....	214	202	202	182	180	S
15	336	6	172	52	22	....	42	114	178	188	172	S
16	338	11	138	35	14	....	57	94	69	237	20	N
17	332	329	46	31	28	....	26	48	31	77	4	N
18	3	331	28	355	17	....	12	33	19	330	4	N
19	340	357	66	37	21	....	21	17	15	356	10	N
20	343	1	51	39	27	....	21	36	22	15	15	N
21	9	349	25	25	12	....	13	17	14	24	1	N
22	297	85	134	162	18	....	175	21	9	215	207	N
23	174	227	247	256	326	....	255	291	302	12	116	N
24	78	173	157	85	336	....	116	118	120	164	168	S
25	283	49	156	82	333	....	27	340	257	342	223	NS
26	169	146	171	165	299	....	175	197	202	335	191	S
27	164	172	191	199	264	....	198	203	195	171	185	S
28	146	186	261	128	232	....	164	171	188	216	176	S
29	191	330	270	18	303	....	337	358	301	18	112	NS
30	146	71	331	170	240	....	186	182	206	9	177	S
31	178	246	297	157	272	....	332	137	341	319	159	NS

TABLE 6—Continued.

NOVEMBER, 1887 (β_1).

Day.	Los Angeles.	Toronto.	Greenwich.	Paris.	Pola.	Prague.	Vienna.	Pawlowsk.	Tiflis.	Zi-Ka-Wei.	Batavia.	
1	**197**	**246**	311	**123**	**97**	....	348	**227**	281	358	325	NS
2	71	346	342	333	....	....	356	6	6	1	353	N
3	**103**	**258**	356	60	55	....	31	82	26	359	2	N
4	**246**	24	354	270	57	....	16	**105**	**123**	21	7	N
5	**262**	1	3	354	48	....	2	56	39	352	345	N
6	293	356	3	0	56	....	14	30	16	4	357	N
7	344	5	353	45	32	....	349	38	21	354	355	N
8	**227**	**189**	2	2	33	....	357	20	26	18	1	N
9	**224**	**264**	359	37	76	....	....	320	19	0	17	N
10	**241**	**198**	**111**	**184**	**175**	....	....	**194**	82	**253**	**186**	S
11	336	10	15	**182**	40	....	**213**	**202**	**125**	**192**	**204**	S
12	38	329	21	**208**	**113**	....	82	63	**116**	69	**125**	N
13	349	9	22	358	....	....	17	9	13	6	354	N
14	339	353	10	356	....	....	16	12	14	0	351	N
15	16	330	69	7	22	....	5	13	16	6	34	N
16	341	347	74	22	22	....	24	22	15	354	345	N
17	30	327	**139**	18	6	....	27	14	13	356	5	N
18	334	**269**	**192**	346	358	....	25	90	**211**	93	**143**	N
19	**252**	**236**	....	62	27	....	46	62	41	323	273	N
20	**129**	**193**	....	**250**	**223**	....	**130**	**199**	**191**	**170**	**186**	S
21	**156**	**146**	....	**212**	**206**	....	....	**225**	**206**	**186**	**172**	S
22	**145**	**177**	**195**	**194**	**209**	....	**199**	**226**	**201**	**177**	**174**	S
23	**140**	**166**	**190**	**195**	**198**	....	**230**	**212**	**195**	**180**	**185**	S
24	79	**193**	**185**	**188**	**204**	....	**185**	**195**	**197**	**182**	**177**	S
25	**99**	**234**	**190**	**187**	**216**	....	**192**	**185**	**188**	**185**	**200**	S
26	5	274	**215**	9	290	....	**242**	**180**	**196**	**180**	**182**	S
27	7	350	11	16	348	....	14	24	9	**191**	347	N
28	2	339	10	14	340	....	17	25	15	**164**	1	N
29	65	**185**	**207**	**268**	**236**	....	**216**	**224**	**208**	**169**	42	S
30	345	69	**192**	348	302	....	8	320	**213**	**176**	**157**	S

DECEMBER, 1887 (β_1).

Day.	Los Angeles.	Toronto.	Greenwich.	Paris.	Pola.	Prague.	Vienna.	Pawlowsk.	Tiflis.	Zi-Ka-Wei.	Batavia.	
1	62	0	**237**	3	**167**	278	358	270	0	5	49	N
2	23	345	9	8	74	286	12	90	13	359	334	N
3	354	344	18	16	66	334	25	21	1	359	13	N
4	352	352	19	16	38	336	22	30	10	357	4	N
5	344	352	20	18	58	345	33	28	15	0	3	N
6	8	**93**	**94**	**108**	51	346	**153**	302	3	357	7	N
7	19	351	**200**	**178**	**176**	278	**194**	90	0	336	284	N
8	354	335	12	25	115	302	49	39	11	9	351	N
9	351	353	354	47	74	306	21	40	12	21	8	N
10	357	357	36	20	35	348	17	40	16	2	4	N
11	353	356	48	24	27	3	26	42	11	355	344	N
12	349	353	17	11	13	1	16	30	10	0	357	N
13	20	**159**	340	**176**	....	**128**	....	**241**	**265**	357	354	N
14	**250**	325	10	12	....	**165**	....	41	**179**	**135**	**166**	NS
15	309	359	18	33	358	332	....	36	11	359	7	N
16	**189**	**159**	**123**	**177**	**183**	**186**	....	**188**	**172**	**120**	**220**	S
17	**136**	**159**	**198**	**203**	....	**203**	**202**	**219**	**148**	**190**	**187**	S
18	**185**	**182**	356	283	....	5	**209**	50	**173**	**167**	**165**	S
19	**121**	**135**	**205**	**204**	....	**232**	**215**	**214**	**138**	**93**	**189**	S
20	**176**	**139**	80	**174**	**200**	278	**242**	**230**	**136**	**184**	**185**	S
21	**169**	**177**	**204**	**218**	**212**	**251**	**210**	**203**	**166**	**186**	**172**	S
22	**188**	**174**	**196**	**193**	**194**	**191**	**195**	**188**	**170**	**175**	**179**	S
23	**176**	336	**191**	**212**	15	**262**	**204**	**176**	**166**	**131**	**182**	S
24	274	347	359	27	12	359	21	61	329	1	**150**	N
25	**169**	306	29	20	....	6	26	38	334	0	355	N
26	**124**	**116**	**208**	**201**	75	**174**	**185**	**256**	**158**	**133**	**179**	S
27	**111**	**256**	**205**	**218**	5	**127**	**206**	**270**	**150**	**205**	**241**	S
28	16	**206**	**205**	286	5	**116**	26	**130**	**188**	25	**206**	NS
29	345	88	**214**	**240**	18	**116**	24	90	**209**	20	**265**	NS
30	317	**140**	**213**	**197**	356	**113**	**145**	1	**159**	303	15	S
31	322	**113**	....	**152**	346	69	70	73	337	29	356	N

While there is some irregularity in certain months, especially May and June, where the impressed magnetic forces always act with minimum power in the Northern Hemisphere—that is, in the summer—the periodic grouping of the N and S values of β_1 is a pronounced phenomenon. Furthermore, it persists certainly through the twelve years 1878–1889 with the same decisiveness as is displayed in 1887. It will be observed that the length of the groups change from N (short) S (long), to S (short) N (long) in the course of the year. This is the first symptom of the phenomenon of inversion, one whose explanation has cost much labor, as it lies at the very foundation of this complex subject. The superiority of this process in determining the magnetic periodicity over the Gaussian least-square method is obvious, because it locates definitely the date of the beginning of the period, and thus gives an epoch from which to make a long run by an ephemeris. The beginning of the period is also independent of inversion, and this is the condition in which the Gaussian method fails. It is now plain, by referring to the normal curve (chart 9), that the peculiar break at the eighth day coincides with the deepest depression in the curve, and that inversion will change the order NS to SN. A complete study of these tables, extending from 1878 to 1889, inclusive, shows that the period of 26.70 days can be usually subdivided into four portions, the divisions coming at the first, the eighth, the fifteenth, and the twenty-first days, respectively. Hence, four parallel groups of dates can be simultaneously determined. The columns NS were collected for the twelve years, 1878–1889, and the divisions between N and S marked as they occur. The apparent irregularities are merely the effects of the forces in their effort to establish the minor typical subdivisions. The common type is, however, a long central portion, with short portions, one at either end, corresponding to the depressions at the sides of the normal curve below the mean value of the vector system.

APPROXIMATE VALUES OF THE 26.68 DAY PERIOD—A TRIAL EPHEMERIS.

The approximate value of the period was computed as follows: Taking the first date of the period, as found by the process described, reduce to a June epoch by adding $26.70 \times n$ days to the given date. These June values are shown for 1878, 1886, 1887, and they indicate the accuracy with which the period tends to recur on individual dates as marked by the azimuth reversals. Counting out the number of revolutions between the epochs found for these years, with the approximate period 26.70, these separate determinations are:

June 16.5, 1878—June 4.0, 1886, 26.692 days, synodic period;
June 16.5, 1878—June 12.2, 1887, 26.683 days, synodic period;
June 4.0, 1886—June 12.2, 1887, 26,657 days, synodic period;

from which 26.68 is taken as the adopted period, with the epoch June 12.22, 1887. From this was constructed the trial ephemeris, whose

January dates for twelve years are given in Table 7. The equation of condition is formed as described in the table.

$$\triangle E + X = D - (E + n\ 26.68)\ \text{residual.}$$

TABLE 7.—*Method of deducing the trial period and ephemeris.*

1878.				1886.		1887.	
Jan. 7	+ 26.7 × 6 =	+ 160.2	June 16.7	Jan. 19	June 1.5	Jan. 5	June 14.2
Feb. 3	× 5	133.5	16.5	Feb. 16	2.8	Jan. 31	13.5
Mar. 1	× 4	106.8	15.8	Mar. 16	4.1	Feb. 25	11.8
Mar. 28	× 3	80.1	16.1	Apr. 12	4.4	Mar. 25	13.1
Apr. 25	× 2	53.4	17.4	May 9	4.7	Apr. 20	12.4
May 23	× 1	26.7	18.7	June 5	5.0	May 18	13.7
June 14	0	0.0	14.0	July 3	6.3	June 13	13.0
July 12	− 26.7 × 1 =	− 26.7	15.3	July 27	3.6	July 7	10.3
Aug. 13	× 2	53.4	20.6	Aug. 23	3.9	Aug. 2	9.6
Sept. 6	× 3	80.1	17.9	Sept. 18	3.2	Aug. 29	9.9
Oct. 1	× 4	106.8	16.2	Oct. 15	3.5	Sept. 26	11.2
Oct. 25	× 5	133.5	13.5	Nov. 12	4.8	Oct. 24	12.5
Nov. 23	× 6	160.2	15.8	Dec. 8	4.1	Nov. 20	12.8
Dec. 21	× 7	186.9	17.1			Dec. 16	12.1
			June 16.5		June 4.0		June 12.2

	Revolutions.	Days.	Synodic period.
1878 June 16.5 to 1886 June 4.0	109	2,909.5	26.692
1878 June 16.5 to 1887 June 12.2	123	3,282.7	26.683
1886 June 4.0 to 1887 June 12.2	14	373.2	26.657

Adopted period, 26.68; epoch, 1887 June 12.22.

EPHEMERIS.

1878—Jan. 8.50	1884—Jan. 5.26
1879—Jan. 17.02	1885—Jan. 12.78
1880—Jan. 25.54	1886—Jan. 21.30
1881—Jan. 6.38	1887—Jan. 3.14
1882—Jan. 14.90	1888—Jan. 11.66
1883—Jan. 23.42	1889—Jan. 19.18

E = adopted epoch; ΔE its correction.
26.68 = adopted period; x its correction.
D = observed date derived as above.
n = number of revolutions from epoch.

$$E + \Delta E + n\ (26.68 + x) = D$$

$$\Delta E + nx = D - (E + n\ 26.68)$$

Residuals.

FOUR PARALLEL SYSTEMS OF DATES; EQUATIONS OF CONDITIONS; NORMAL EQUATIONS AND SOLUTION.

In the next Table 8, under the head "Observation dates," are collected the four parallel systems of dates, all reduced to June, which were derived from the systems of NS reversals in azimuth of the angle β_1. In each year only such individual dates were admitted to this computation as showed a clearly marked, abrupt transition. Thus in 1887 two or three dates were omitted in the summer, which changed the mean epoch from June 12.22 to June 12.87. The mean interval elapsed between the successive sets I, II, III, IV is 7.60, 9.29, 5.17 days, respectively, and those values are employed in taking out the corresponding dates from the provisional ephemeris $E + n \times 26.68$. The residuals are $D - (E + n \times 26.68)$ and are arranged in four parallel columns. The equations of condition are $\Delta E + nx = D - (E + n\ 26.68)$. Each solution I, II, III, IV is conducted separately, and the four values in the solutions for ΔE and x are given.

TABLE 8.—*Formation and solution of the equations of condition.*

Year.	Observation dates (D). [Mean for June.] I.	II.	III.	IV.	Ephemeris dates. [E + n 26.68.] I.	II.	III.	IV.	Residuals [D—(E + n 26.68)]. I.	II.	III.	IV.	Revolutions. (n)
1878	18.00	26.21	35.67	41.25	17.58	25.18	34.47	39.64	+0.42	+1.03	+1.20	+1.61	—123
1879	1.54	8.39	16.70	22.73	30.42	38.02	47.31	52.48	+1.12	+0.37	+0.61	+0.25	—110
1880	7.97	15.64	26.21	30.70	6.94	14.54	23.83	29.00	+1.03	+1.10	+2.38	+1.70	— 96
1881	16.76	23.66	33.06	38.78	15.46	23.06	32.35	37.52	+1.30	+0.60	+0.71	+1.26	— 82
1882	25.40	33.36	41.95	46.64	23.98	31.58	40.87	46.04	+1.42	+1.78	+1.08	+0.60	— 68
1883	6.84	14.56	23.91	28.53	5.82	13.42	22.71	27.88	+1.02	+1.14	+1.20	+0.65	— 55
1884	14.68	22.55	31.69	36.64	13.34	20.94	30.23	35.40	+1.34	+1.61	+1.46	+1.24	— 41
1885	21.70	30.54	39.94	44.82	21.86	29.46	38.75	43.92	—0.16	+1.08	+1.19	+0.80	— 27
1886	4.52	11.35	21.59	26.81	3.70	11.30	20.59	25.76	+0.82	+0.05	+1.00	+1.05	— 14
1887	12.87	20.16	30.03	35.42	**12.22**	**19.82**	**29.11**	**34.28**	+0.65	+0.34	+0.92	+1.14	0
1888	20.98	29.02	36.77	41.70	19.74	27.34	36.63	41.80	+1.24	+1.68	+0.14	—0.10	+ 14
1889	3.00	9.99	19.34	24.86	1.58	9.18	18.47	23.64	+1.42	+0.81	+0.87	+1.22	+ 27
	12.85	20.45	29.74	34.91									
	7.60	9.29	5.17										

Equations of condition.

ΔE	nx	$x+\Delta E$	I.—Residual.
a	b	s	(n)
1	—123	—122	—0.42 = 0
1	—110	—109	—1.12 = 0
1	— 96	— 95	—1.03 = 0
1	— 82	— 81	—1.30 = 0
1	— 68	— 67	—1.42 = 0
1	— 55	— 54	—1.02 = 0
1	— 41	— 40	—1.34 = 0
1	— 27	— 26	+0.16 = 0
1	— 14	— 13	—0.82 = 0
1	0	+ 1	—0.65 = 0
1	+ 14	+ 15	—1.24 = 0
1	+ 27	+ 28	—1.42 = 0

Normal equations.	Solutions.	Means.
I.	I.	
$12\,\Delta E - 575x - 11.62 = 0$	$\Delta E = +0.99948$	$\Delta E + 0.93375$
$-575\,\Delta E + 54349x + 539.40 - 0$	$x = +0.00065$	$x = -0.00072$
II.	II.	
$12\,\Delta E - 575x - 11.62 = 0$	$\Delta E = +0.96881$	
$-575\,\Delta E + 54349x + 556.41 = 0$	$x = +0.00001$	
III.	III.	
$12\,\Delta E - 575x - 11.62 = 0$	$\Delta E = +0.91615$	
$-575\,\Delta E + 54349x + 585.98 = 0$	$x = -0.00109$	
IV.	IV.	
$12\,\Delta E - 575x - 11.62 = 0$	$\Delta E = +0.85054$	
$-575\,\Delta E + 54349x + 622.59 = 0$	$x = -0.00246$	

Corrected period, $26.67928^{d} = 26^{d}\,16^{h}\,18^{m}\,9.8^{s}$ synodic.
$24.86319^{d} = 24^{d}\,20^{h}\,42^{m}\,59.6^{s}$ siderial. Daily motion, 868.7′.

Corrected epoch, June 12.22 + 0.93 + 0.57 = June 13.72, 1887.

The mean correction for the epoch June 12.22, 1887, is +0.93375, and the mean correction to the period 26.68 days is −0.00072. The resulting period is—

$$26.67928^{d} = 26^{d}\ 16^{h}\ 18^{m}\ 9.8^{s}\ \text{synodic.}$$
$$24.86319^{d} = 24^{d}\ 20^{h}\ 42^{m}\ 59.6^{s}\ \text{siderial.}$$

The mean daily siderial motion is 868.7′.

Further experience with the normal curve has induced me to change the epoch June 12.22 by +0.93, also +0.57 (arbitrary). This latter correction does two things: It throws the epoch squarely upon one of the rectangular axes of the normal curve, to be described hereafter, and it matches better with the American weather system, counting the Dakota region as one day elapsed. Being a practical adjustment of the epoch only, and not affecting the period, it has its justification in experience. My final ephemeris has the epoch June 13.72, 1887, and the period 26.67928 days. (See Bulletin No. 20.)

The periodic action of azimuth reversal within the terrestrial magnetic field is therefore the exclusive basis of the adopted period. The inference that it is the effect of the direct continuous magnetic action of the sun is so obvious as to go without saying, (1) because no other known agency is capable of producing such a persistent periodicity, and (2) because the period itself is in agreement with the known approximate period of revolution of the sun at the equator, as determined by observations on the sun spots. Thus we have, as in Table 1:

	Siderial.
	′
Carrington's motion at the sun's equator	867.0
Spoerer's motion at the sun's equator	881.5
Faye's motion at the sun's equator	863.0
Tisserand's motion at the sun's equator	858.0
Mean motion at the sun's equator	867.4

The arithmetical mean of these four results is 867.4′, and happens to agree with my determination within 1.3′ arc, sufficiently close to afford strong presumptive evidence that the rotation of a solar nucleus is at the basis of the two types of phenomena, one on the sun and one on the earth.

Chapter 3.

ANALYSIS OF THE POLAR MAGNETIC FIELD ALONG THE TERRESTRIAL MERIDIANS.

EXAMPLE OF THE COMPUTATION FOR FORT RAE.

Having shown the method of discussing the observations, and the fact that these disclose a periodicity in the variations of the actual field on the normal, as measured by the impressed vectors, we proceed to elaborate this vector system, especially in north and south lines. The average angle that the vectors make with the horizontal plane in Europe is about 40 degrees, and they act nearly along the magnetic meridians. Hence the variations of the horizontal component becomes the simplest index of the state of the impressed field at any station, and would be a complete indication of the same if the vertical angle was always constant. There is, however, much irregular disturbance in the lines of the earth's field, and it is necessary to resort to averages at each station to determine the vectors of the mean deflecting system.

It was found that the magnetic observations, complete in the three elements for a year, were available at twenty-six stations, whose names and magnetic latitude are given in Table 10, as well as the year from which the observational data was extracted. As Kingua Fjord has some gaps in the vertical force, Fort Rae is selected as the station for a specimen of the work, which is found in Table 9.

TABLE 9.—*Deflecting forces separated into southward and northward groups.*

Station: Fort Rae. ($4^h\ 43^m$ W.; $+62°\ 39'$ N.)

[β = magnetic azimuth. α = vertical angle. s = total. σ = horizontal (5th).]

	β	α	s	σ		β	α	s	σ		β	α	s	σ
1882.					1882.					1882.				
Sept. 12	186	−59	53	28	Oct. 8	20	46	70	48	Nov. 4	6	−75	D	63
13	230	58	42	24	9	39	- 40	33	25	5	9	−62	D	90
14	220	30	28	24	10	0	88	28	1	6	4	−62	D	68
15	232	11	29	28	11	58	0	9	9	7	292	−83	D	15
16	225	−82	65	8	12	45	3	20	20	8	13	−61	91	43
17	304	−27	4	4	13	26	30	29	25	9	225	−35	48	38
18	297	−28	2	2	14	210	−66	77	35	10	350	−42	70	52
19	204	30	20	17	15	200	14	92	90	11	292	47	33	22
20	204	44	32	22	16	41	0	30	30	12	183	67	D	68
21	241	73	36	10	17	332	35	32	25	13	214	68	D	127
22	292	69	26	8	18	25	38	30	23	14	245	74	D	53
23	160	50	48	30	19	10	−39	32	24	15	317	−81	D	33
24	76	−7	21	21	20	20	−40	44	34	16	14	−75	D	70
25	216	69	90	30	21	27	−62	55	27	17	183	−19	D	D
26	154	−13	36	35	22	340	−60	30	12	18	218	−45	92	72
27	257	18	9	9	23	172	−32	48	40	19	192	−7	D	D
28	180	−85	46	4	24	155	−63	50	24	20	216	71	92	30
29	202	−20	40	36	25	70	−78	45	9	21	218	44	52	38
30	129	−70	45	14	26	24	−75	105	22	22	260	25	87	78
Oct. 1	106	−44	38	26	27	55	−80	73	12	23	349	40	72	55
2	123	85	132	11	28	330	−73	23	6	24	159	−15	53	51
3	66	−39	19	15	29	180	−83	9	1	25	129	25	41	36
4	182	8	66	65	30	320	7	16	16	26	279	−75	46	12
5	188	−29	100	86	31	14	48	32	32	27	49	37	25	20
6	187	53	115	69	Nov. 1	3	75	26	22	28	10	72	80	25
7	20	0	30	30	2	14	54	128	75	29	30	59	65	35
					3	8	−15	54	19	30	20	20	43	41
	[Group means.]					[Group means.]					[Group means.]			
S	191	+6	54	29	S	183	−46	55	38	S	204	+21	66	59
N	356	−9	17	13	N	17	−6	43	22	N	353	23	58	43

TABLE 9.—*Deflecting forces separated into southward and northward groups*—Continued.

Station: Fort Rae. ($4^h\ 43^m$ W.; $+62°\ 39'$ N.)

[β = magnetic azimuth. α = vertical angle. s = total. σ = horizontal (5th).]

Period.	Southward.				Northward.			
	β	α	s	σ	β	α	s	σ
1882.								
Sept. 12	191	+ 6	54	29	356	− 9	17	13
Oct. 8	183	− 46	55	38	17	− 6	43	22
Nov. 4	204	+ 21	66	59	353	−23	58	43
Dec. 1	173	− 5	31	19	14	−25	63	34
Dec. 27	165	+ 23	38	21	6	−32	43	17
1883.		+ 47						
Jan. 23	202		46	20	17	+28	52	27
Feb. 19	191	+ 14	58	44	357	+23	34	25
Mar. 17	177	+ 30	45	20	3	+39	43	21
Apr. 13	161	− 2	40	23	5	−27	38	16
May 10	196	− 11	37	30	5	−15	23	17
June 5	203	+ 9	37	26	7	−31	29	23
July 2	208	+ 5	39	26	13	−21	31	19
July 29	212	+ 11	54	36	354	− 7	31	13
Annual mean	190	+ 8	46	30	5	− 8	39	22

The year is broken up into periods of 26.68 days, in accordance with the Ephemeris, and the $\sigma\ s\ \alpha\ \beta$ computed for each date. These are separated into two groups, the southward (heavy type) and the northward (light type), as indicated by the angles β, and the means for each group in every period are taken. These means are then collected respectively under the southward and northward headings and the means taken again. This latter set of values gives the average vector for the year at Fort Rae, as it points respectively toward the south or toward the north. In a few cases the excessive disturbances are omitted from the sums that afford the mean values in the individual periods. The chief difficulty in discussing the angle α arises from the fact that oftentimes the small or insignificant values in the variations dx, dy, dz produce very large values of α, especially if the denominator happens to be a little number. But in fact the values of α should properly be derived from only the strong values of these coordinates. These large values of α may offset many correct values, if the true angle α happens to be small, since the plus and minus signs must be observed throughout. It is concluded that the average sign of α indicates the fact of entry or emergence of the vector, while the true values of the angle can be better obtained from σ, s, as has been already done for the European stations.

In the case of Fort Rae, 1882–83, the southern vector, $\beta=190°$, enters the earth at the angle ($\cos\alpha=\frac{30}{46}$), $\alpha=49°\ 18'$, and the northward emerges, $\beta=5°$, at the angle ($\cos\alpha=\frac{22}{39}$), $\alpha=55°\ 40'$. We must conceive that the earth's magnetic field is, while under the influence of impressed impulses, compelled to adjust itself, so far as these vectors go, along a definite path, at the given station. The normal field may be subject to other vectors derived from other sources; these vectors may be of very short or very long duration, for it is evident that the normal field suffers incessant variations, which may be analyzed in the

way thus explained. Such a study ought some time to be carefully made for the several stations, and thus render very accurate the results which are derived approximately in this paper.

TABLE 10.—*Mean deflecting vectors at twenty-six stations.*

No.	Station.	Magnetic latitude.	Year.	Mean values.								Adjusted values.					
				South.				North.				South.			North.		
				β	α	s	σ	β	α	s	σ	s	σ	α	s	σ	α
		°												°			
1	Kingua Fjord ...	77.9	1882	161	+ 5	45	27	337	— 6	37	23	45	28	54	38	23	54
2	Fort Rae	76.0	1882	190	+ 8	46	30	5	— 8	39	22	53	29	55	43	24	55
3	Point Barrow ...	73.1	1882	180	— 6	59	29	4	+ 5	55	29	60	30	58	52	24	58
4	Cap Thordsen...	71.1	1882	186	—14	62	28	6	+ 8	50	23	59	30	59	52	23	59
5	Jan Mayen......	68.8	1882	180	+10	54	29	4	— 9	44	22	55	27	60	49	22	60
6	Bossekop	64.4	1882	188	+14	43	29	18	— 6	33	19	42	23	58	33	17	58
7	Toronto	62.2	1847	176	—28	32	18	356	+27	25	11	34	18	55	26	13	55
8	Sodankyla	61.4	1882	184	+ 5	16	15	14	— 2	14	12	31	15	54	24	11	54
9	Washington	55.6	1890	179	+19	18	7	357	0	20	8	20	12	48	14	8	48
10	Pawlowsk	55.1	1882	196	+10	12	10	15	— 9	10	8	18	10	47	13	8	47
11	Greenwich	50.4	1887	175	— 6	13	9	359	+ 1	13	9	14	9	43	10	7	43
12	Parc St. Maur...	47.3	1884	177	+ 2	12	9	357	— 4	11	8	13	10	41	10	8	41
13	Vienna...........	44.8	1882	178	+ 5	19	15	1	— 1	20	16	14	11	40	11	9	40
14	Pola..............	41.7	1892	183	+14	23	16	1	— 6	17	11	16	12	38	12	9	38
15	Los Angeles	40.3	1883	181	+10	22	12	0	— 8	23	10	17	13	37	13	10	37
16	Tiflis.............	36.1	1882	182	+ 6	15	12	13	— 7	13	11	23	19	37	17	16	37
17	Zi-ka-wei	27.6	1882	187	— 4	42	32	351	+ 5	33	23	38	27	43	32	23	43
18	Bombay	9.9	1863	182	+ 4	36	20	3	— 5	33	16	31	20	53	25	15	53
19	Madras...........	3.8	1855	185	+ 2	13	11	349	— 1	12	10	19	14	36	15	11	36
20	Singapore	— 6.4	1845	182	— 2	14	11	359	— 8	12	10	15	11	39	11	8	39
21	St. Helena.......	—11.2	1843	178	—10	17	9	349	— 2	17	8	16	10	57	12	7	57
22	Batavia	—15.1	1890	182	+13	16	8	1	—12	16	9	22	12	58	15	8	58
23	Süd Georgien ...	—29.8	1882	187	+26	52	20	8	—17	47	15	36	19	47	31	16	47
24	Cape Horn	—33.5	1882	176	— 2	15	13	6	+ 4	13	10	25	13	44	19	10	44
25	Cape Good Hope	—33.9	1842	185	+16	19	11	353	— 3	16	11	20	12	43	15	9	43
26	Hobarton	—54.8	1842	176	+22	26	15	0	—27	22	13	26	14	52	22	12	52

EXTENSION OF THE COMPUTATION TO TWENTY-SIX STATIONS.

In Table 10 are collected similar "mean values" for twenty-six stations in different magnetic latitudes. The angle β shows that the vectors cling closely to the magnetic meridians; the angle α indicates that the southward vectors tend to enter and the northward to emerge in the northern hemisphere; the southward angles are more firmly developed, the vectors σ and s being almost always stronger to the south than to the north, which amounts to saying that the heavier disturbances are directed southward, and that the positive source of the external field is to the north of the plane of the ecliptic. In order to obtain the "adjusted values," the mean values of σ, s, α were plotted as ordinates along a line of abscissas extending from 0° to 180° polar distance, and an average curve drawn through them. It was not thought worth while, in the preliminary stages of the research, to attempt a more refined discussion.

DISCUSSION OF THE RESULTS.

To show the relations of these adjusted values to a mean magnetic meridian, they are distributed on Chart 10 along a circle at the angles α and lengths s, the foot of each vector standing on the station as located by its magnetic latitude. The curved bounding line shows the average

strength of the impressed vectors. The system has two maxima in each hemisphere—one over the auroral belt and the other over the trop-

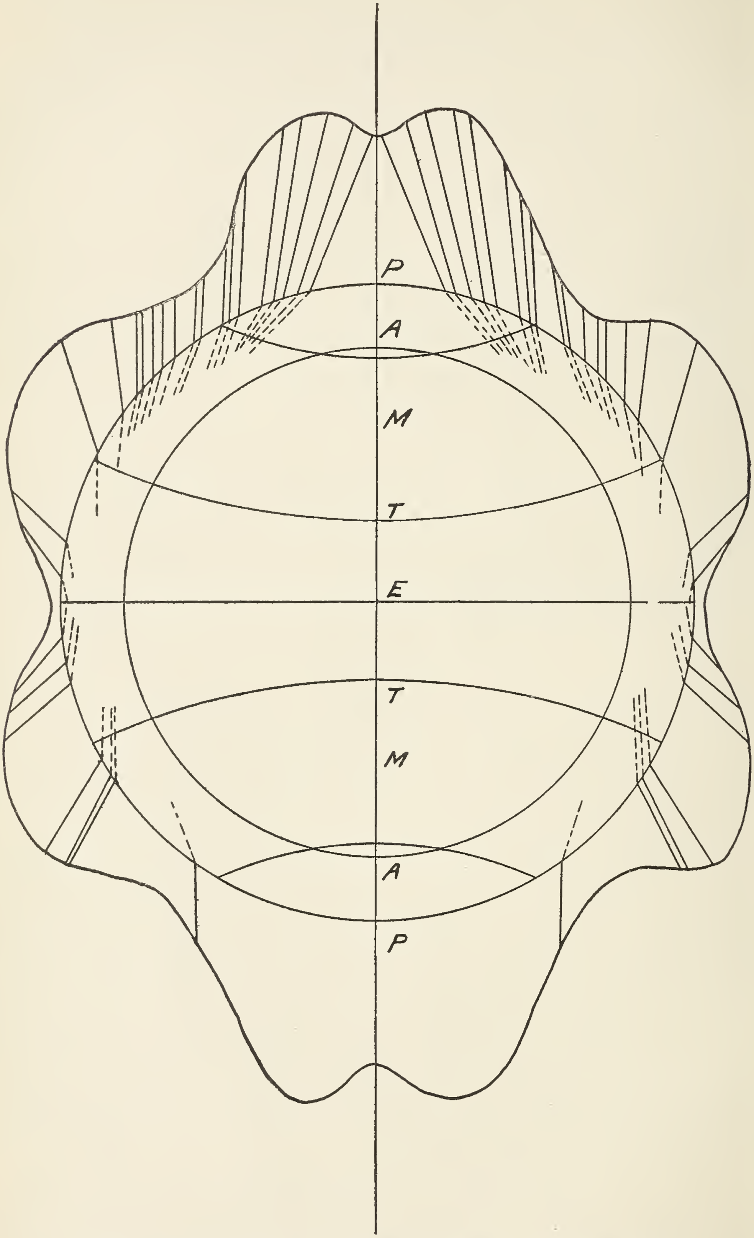


CHART 10.—Vectors of the polar magnetic field derived from observations.
[$\mu=2.0$. $H=0.00035$.]

ics; it has three minima—one over the poles, a deeper one over the mid-latitudes, and a third, with very small values, at the equator. The

sweep away from the poles suggests the explanation of the *aurora*, as a concentration of the impressed external magnetic force in the isochamen ovals, which also falls off in the midlatitude zones. The aspect of this vector system suggests also the theory of the entire phenomenon, namely, that the earth's shell is to some extent permeable, and is plunged in an external magnetic field whose lines of force are distorted from being parallel at a distance from the earth into the curves imposed by such a well-known magnetic system.

FORMULÆ FOR THE MAGNETIC SYSTEMS.

A set of formulæ are here collected together on Table 11 to cover the several cases arising in these problems, whose consequences can readily be followed out. Formulæ (1) for a uniformly magnetized sphere; (2) for a uniformly magnetized sphere in a uniform field, each referred to the axis x; (3) the inflected and exflected systems arising according to the type of permeability. When the axis of the sphere is not parallel to the lines of the external field, this can be resolved parallel and perpendicular to the axis of the magnetization and be brought under these formulæ.

Table 11.

1. FORMULÆ FOR A UNIFORMLY MAGNETIZED SPHERE.

[Referred to the polar axis x.]

Potential: $V = \frac{m}{r} - \frac{m}{r^1} = m\frac{r^1 - r}{rr^1} = m\frac{r^1 - r}{r^2} = \frac{4}{3}\pi R^3 I \frac{\cos\theta}{r^2} = \frac{4}{3}\pi R^3 I \frac{x}{r^3} = \tilde{\omega}\frac{\cos\theta}{r^2} = \tilde{\omega}$ solid angle θ.

Line of force: $N = 2\pi m(\cos\theta^1 - \cos\theta) = 2\pi . \frac{4}{3}\pi R^3 I . \frac{\sin^2\theta}{r} = 2\pi . \frac{4}{3}\pi R^3 I . \frac{y^2}{r^3}$.

Asymptote: $\tan^2\theta = 2 = \cot^2\phi$.

Moment: $\tilde{\omega} = 2\,ma = \frac{4}{3}\pi R^3 . I = -R^3 F_i = -R^3\frac{F_e}{2} = R^3\frac{\mu - 1}{\mu + 2}H = \frac{F_\phi R^3}{\sqrt{3\sin^2\phi}}$.

Surface of cap: $2\,\theta = 2\pi R^2(1 - \cos\theta)$.

Element zone: $d\,S = 2\pi R^2 \sin\theta\, d\,\theta$.

Flow of force: $d\,Q = 4\pi . \frac{4}{3}\pi R^3 I \frac{\sin\theta\cos\theta\, d\,\theta}{r}$.

Total flow: $Q_\theta = 2\pi . \frac{4}{3}\pi R^3 I . \frac{\sin^2\theta}{r}$.

Flow through positive layer $= 4\pi M = 4\pi R^2 . \pi I = -4\pi R^2 . \frac{3}{4} F_i = -3\pi R^2 F_i$.

Flow through great circle $= \frac{8}{3}\pi I . \pi R^2 = \frac{8}{3}\pi^2 R^2 I$.

Mass of element zone $I\,d\,S = d . \pi R^2 I \sin^2\theta$.

Mass of each layer $M = \int_0^{\frac{\pi}{2}} I\,d\,S = \pi R^2 I = \frac{3}{4} . \frac{4}{3}\pi\frac{R^3}{R} I = -\frac{3}{4} F_i R^2$.

2. UNIFORMLY MAGNETIZED SPHERE IN A UNIFORM FIELD.

[Each referred to the axis x.]

Internal: $\mathrm{V_i} = \frac{4}{3}\pi\,\mathrm{I}\,x = \frac{4}{3}\pi\frac{\mathrm{R}^3}{r^3}\mathrm{I}\,x = -\mathrm{F_i}\,x = -\mathrm{F_i}\,r\cos\theta.$

$$-\mathrm{F_i} = \frac{4}{3}\pi\rho\delta = \frac{4}{3}\pi\mathrm{I}.$$

External: $\mathrm{V_e} = \frac{4}{3}\pi\mathrm{R}^3\mathrm{I}\frac{\cos\theta}{r^2} = \frac{4}{3}\pi\mathrm{R}^3\mathrm{I}\frac{x}{r^3} = -\mathrm{F_i}\frac{\mathrm{R}^3}{r^3}x = -\mathrm{F_i}\,\mathrm{R}^3\frac{\cos\theta}{r^2}.$

$$\mathrm{F_x} = \mathrm{X} = -\frac{d\mathrm{V}}{dx} = -\frac{4}{3}\pi\mathrm{R}^3\mathrm{I}.\frac{1}{r^3}\left(1-\frac{3x^2}{r^2}\right) = -\frac{4}{3}\pi\mathrm{R}^3\mathrm{I}\left(\frac{1-3\cos^2\theta}{r^3}\right) = \mathrm{F_i}\frac{\mathrm{R}^3}{r^3}\left(1-3\cos^2\theta\right).$$

$$\mathrm{F_y} = \mathrm{Y} = -\frac{d\mathrm{V}}{dy} = +\frac{4}{3}\pi\mathrm{R}^3\mathrm{I}\frac{1}{r^3}\frac{3xy}{r^2} = \frac{4}{3}\pi\mathrm{R}^3\mathrm{I}\frac{3\sin\theta\cos\theta}{r^3} = -\mathrm{F_i}\frac{\mathrm{R}^3}{r^3}3\sin\theta\cos\theta.$$

$$\mathrm{F_n} = \mathrm{X}\cos\theta + \mathrm{Y}\sin\theta = \frac{4}{3}\pi\mathrm{R}^3\mathrm{I}\frac{2\cos\theta}{r^3} = \frac{4}{3}\pi\mathrm{R}^3\mathrm{I}\frac{2x}{r^4} = -2\,\mathrm{F_i}\frac{\mathrm{R}^3}{r^3}\cos\theta.$$

$$\mathrm{F_t} = -\mathrm{X}\sin\theta + \mathrm{Y}\cos\theta = \frac{4}{3}\pi\mathrm{R}^3\mathrm{I}\frac{\sin\theta}{r^3} = \frac{4}{3}\pi\mathrm{R}^3\mathrm{I}\frac{y}{r^4} = -\mathrm{F_i}\frac{\mathrm{R}^3}{r^3}\sin\theta.$$

$$\mathrm{F}_\phi^2 = \mathrm{X}^2+\mathrm{Y}^2 = \mathrm{F}_n^2+\mathrm{F}_t^2 = \left(\frac{4}{3}\pi\frac{\mathrm{R}^3}{r^3}\mathrm{I}\right)^2\left(3\cos^2\theta+1\right) = \left(\frac{3}{4}\pi\frac{\mathrm{R}^3}{r^3}\mathrm{I}\right)^2\left(3\sin^2\phi+1\right) = \left(\frac{4}{3}\pi\frac{\mathrm{R}^3}{r^3}\mathrm{I}\right)^2\left(\frac{\mathrm{OQ}}{\mathrm{OS}}+1\right).$$

$$\mathrm{F_e} = \frac{\mathrm{F_p}}{2} = \frac{4}{3}\pi\frac{\mathrm{R}^3}{r^3}\mathrm{I} = \frac{4}{3}\pi\mathrm{I}.$$

$$\mathrm{F_p} = 2.\frac{4}{3}\pi\frac{\mathrm{R}^3}{r^3}\mathrm{I} = 2\,\mathrm{F_e} = \frac{2\varpi}{r^3}.$$

TABLE 11—Continued.

3. INFLECTED AND EXFLECTED MAGNETIC SYSTEMS.

[Referred to the axis x.]

Potential: $^{\mathrm{i}}V_{\mathrm{e}}^{\mathrm{e}} = \pm R^3 \frac{\mu - 1}{\mu + 2} H \frac{x}{r^3} - Hx.$ $\qquad V_{\mathrm{i}}^{\mathrm{i}} = -\frac{3}{\mu + 2} Hx. \qquad V_{\mathrm{i}}^{\mathrm{e}} = -\frac{2\mu + 3}{\mu + 2} Hx.$

Force: $^{\mathrm{i}}X_{\mathrm{e}}^{\mathrm{e}} = \mp R^3 \frac{\mu - 1}{\mu + 2} \frac{H}{r^3} \left(1 - \frac{3x^2}{r^2}\right) + H.$

$$^{\mathrm{i}}Y_{\mathrm{e}}^{\mathrm{e}} = \mp R^3 \frac{\mu - 1}{\mu + 2} \frac{H}{r^3} \left(1 - \frac{3xy}{r^2}\right).$$

$$^{\mathrm{i}}Z_{\mathrm{e}}^{\mathrm{e}} = \mp R^3 \frac{\mu - 1}{\mu + 2} \frac{H}{r^3} \left(1 - \frac{3xz}{r^2}\right).$$

$^{\mathrm{i}}X_{\mathrm{e}}^{\mathrm{e}} = \pm 2 R^3 \frac{\mu - 1}{\mu + 2} \frac{H}{r^3} + H.$ $\qquad$ On the axis x $(x = r)$.

$X_{\mathrm{o}}^{\mathrm{i}} = \frac{3\mu}{\mu + 2} H = H_1^{\mathrm{i}}$; $X_{\mathrm{o}}^{\mathrm{e}} = \frac{4 - \mu}{\mu + 2} H = H_1^{\mathrm{e}}.$ $\qquad$ At the surface on axis x $(x = r = R)$.

$$^{\mathrm{i}}X_{\mathrm{i}}^{\mathrm{e}} = \mp R^3 \frac{\mu - 1}{\mu + 2} \frac{H}{r^3} + H.$$

Magnetization: $I = \pm \frac{3}{4\pi} \frac{\mu - 1}{\mu + 2} \frac{H}{R} x.$ $\qquad$ Line of force: $N = \pm \frac{\varpi p^2}{r^3} + \frac{1}{2} H p^2.$

Permeability: $\mu = \dfrac{2\left(1 \pm \dfrac{8\pi}{3}\dfrac{I}{H}\right)}{2 \mp \dfrac{8\pi}{3}\dfrac{I}{H}}$.

Coordinates: $x^2 = \pm \left[\dfrac{2\,R^3 \dfrac{\mu - 1}{\mu + 2} y^2}{\dfrac{2\,N}{H} - y^2} \right]^{\frac{2}{3}} - y^2$.

Refraction: $H_1 \sin\theta_1 = H_2 \sin\theta_2$. Tangential.

$\mu_1 H_1 \cos\theta_1 = \mu_2 H_2 \cos\theta_2$. Normal.

$\mu_2 \tan\theta_1 = \mu_1 \tan\theta_2$.

Sub. *e. o. i* = external, surface, internal, respectively.

Super. *i. e.* = inflected, exflected, respectively.

Upper sign = inflected.

Lower sign = exflected.

Moment $M = H \dfrac{(\mu - 1)}{\mu + 2} R^3$.

CHART OF COMBINED EXFLECTED AND INFLECTED SYSTEMS.

A rough mean integration of the length of the vectors s shows that the external uniform field averages, H = 0.00035 C. G. S.; trial computations bring the permeability to about 2; R can be taken as unity for a type figure; successive values may be assigned to the lines of force N, from the formula $x^2 = \pm \left[\dfrac{0.50y^2}{y^2 - \dfrac{2\,\mathrm{N}}{35}}\right]^{\frac{2}{3}} - y^2,$

the coordinate values of several lines may be computed. By this process we draw chart 11, and it is only necessary to compare it with chart 8 to be assured that we have the same fundamental phenomenon.

Table 12.

COMPUTED ORDINATES y.

	Exflected.							Inflected.				
N =	0.0	0.5	1	2	4	6	8	10	15	20	24	27
x = 0	.80	.81	.82	.83	.87	.92	.95	.....	.....	......	......	.80
.1	.79	.80	.81	.82	.86	.92	.95	.....	.....	......	......	.88
.2	.77	.78	.80	.81	.85	.91	.94	.....	.....	......	.82	.95
.3	.74	.75	.77	.80	.83	.90	.93	.....	.....	.78	.89	1.00
.4	.68	.70	.72	.77	.81	.88	.92	.....	.....	.83	.94	1.05
.5	.61	.64	.67	.71	.78	.85	.90	.....	.64	.87	.99	1.09
.6	.52	.57	.60	.65	.72	.81	.87	.50	.70	.90	1.02	1.13
.7	.38	.44	.50	.57	.68	.77	.84	.55	.75	.93	1.04	1.15
.8	.....	.34	.41	.50	.63	.73	.82	.60	.78	.95	1.06	1.17
.9	.....	.28	.35	.46	.60	.71	.80	.62	.81	.97	1.08	1.19
1.0	.....	.24	.31	.42	.58	.69	.78	.64	.83	.98	1.09	1.20
1.1	.....	.21	.30	.40	.56	.67	.77	.66	.85	.99	1.10	1.21
1.2	.....	.20	.29	.39	.54	.64	.74	.67	.86	1.00	1.10	1.22
1.5	.....	.19	.27	.38	.50	.61	.71	.69	.89	1.03	1.11	1.23
2.0	.....	.18	.25	.34	.49	.60	.69	.71	.91	1.04	1.12	1.24

$$x^2 = \left[\frac{0.50\,y^2}{y^2 - \dfrac{2\,\mathrm{N}}{35}}\right]^{\frac{2}{3}} - y^2. \qquad\qquad x^2 = \left[\frac{0.50\,y^2}{\dfrac{2\,\mathrm{N}}{35} - y^2}\right]^{\frac{2}{3}} - y^2.$$

It indicates that the nucleus of the earth is impenetrable to the lines of this magnetic field, and that hence they are exflected as by an obstacle, and pass around it; but the shell, having a thickness of about 800 miles, is slightly permeable, and collects the external lines within itself, as the easiest path for the transference of external energy. At the surface, for both branches of the system where the two media meet, the law of magnetic refraction applies.

$$\mu_2 \tan \theta_1 = \mu_1 \tan \theta_2.$$
$$\mathrm{H}_1 \cos \theta_1 = 2\ \mathrm{H}_2 \cos \theta_2, \text{ normal component.}$$
$$\mathrm{H}_1 \sin \theta_1 = \mathrm{H}_2 \sin \theta_2, \text{ tangential component.}$$

The tangential components in each media are equal, while the normal change in the ratio of permeability. It is not possible to draw these vector lines perfectly, that is, to obtain the value of μ exactly, unless the internal paths of the system are known, but the approximation is so close as to give confidence in the main proposition.

Whenever the strength of the external field changes for any cause, the impressed vector at a given station varies proportionally along the

paths thus laid down; if it oscillates back and forth irregularly, it will produce such an effect as is recorded on the traces of magnetic observations; if it oscillates back and forth periodically, a wave motion is

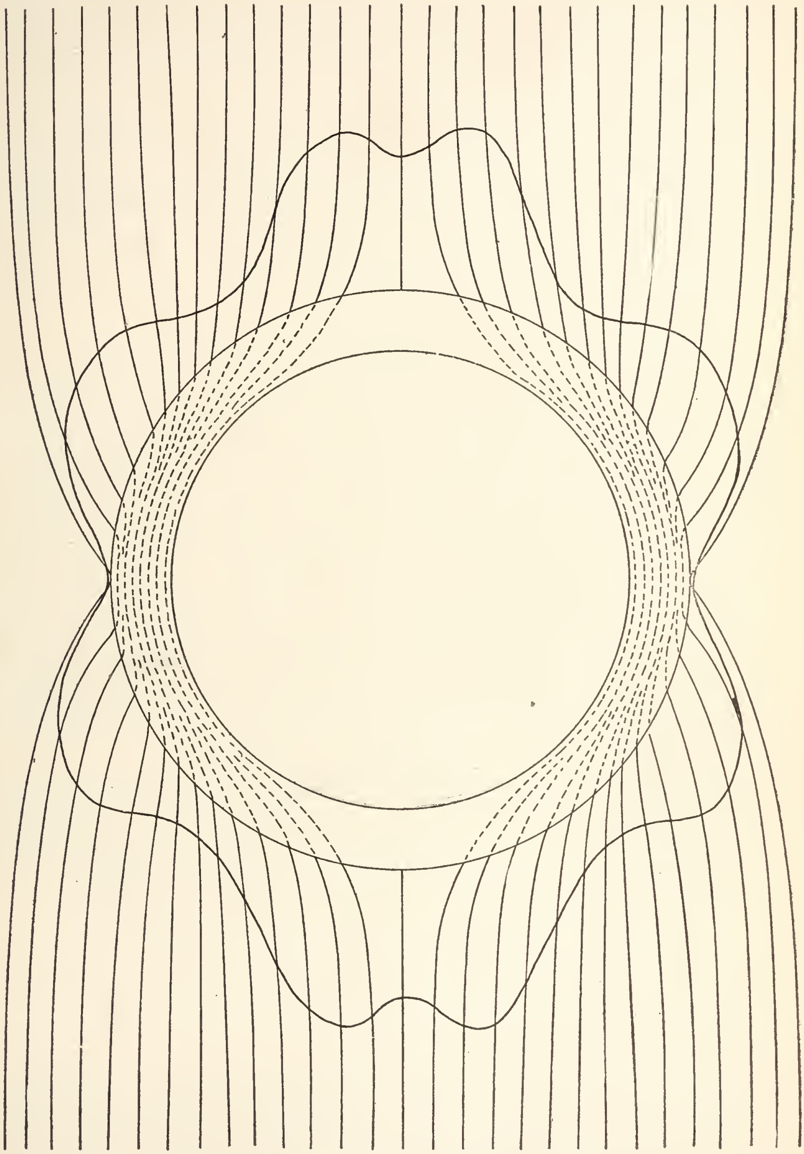


CHART 11.—Magnetic lines through a permeable shell.

set up in what would otherwise be a steady field; if the great impulses come from the north to south, then the source of energy must be to the north and the sink to the south of the ecliptic. Such oscillations,

aperiodic or periodic, are accompanied by transient induced electric currents, and the transfer of energy may be called a *radiation;* half of this energy is turned into heat and the other half into the setting up the new magnetic field by means of these transient magnetic and electric currents. Such energy may be one source of atmospheric electricity and also of the earth electric currents, especially during excessive oscillations.[1]

The attendant electric phenomena in the earth's atmosphere and crust I have had little time to investigate; and indeed it is very hard to discuss them satisfactorily, because of the difficulty of securing the observations in vector form. Also concerning induced magnetic currents derived from the motions of the earth or the air currents, no special studies have been made, though the subject should be worked up if it is possible to do so definitively.

DISTURBING VECTORS DURING GREAT DISTURBANCES.

Having given examples of the vectors of the polar field taken, (1) for intervals of twenty-four hours, and (2) by the year, it is proper to also show their behavior at the same instant of time for widely separated stations. This discussion will be based upon the instantaneous impulses without the summation involved in the diurnal, the 26.68-day intervals, and the annual periods. For this purpose the three disturbances of January 4, January 28, and February 13, 1892, have been computed by the methods employed above. The directors of the observatories at San Antonio, Toronto, Washington, Greenwich, Paris, Potsdam, Vienna, Pawlowsk, Zi-ka-wei, and Melbourne had the courtesy to place at the service of the Weather Bureau the traces of their magnetic elements and the reduction constants for the required dates, and this cooperation is hereby acknowledged with thanks.

On making a comparative study of the material it was found that many differing forms of arrangement of the apparatus are employed in the observatories, so that the reduction of the data was very laborious, because of the care required in passing from station to station.

DIFFERENT SYSTEMS OF INSTRUMENTAL RECORDS.

TABLE 13.—*Arrangement of the photographic traces.*

Station.	Long.	Lat.	Trace.	Change.	Base line—Trace—Ordinates. H.	D.	V.
	h	°	*cm.*				
San Antonio ..	6.6 W.	+29.4	37	10 a. m.	Below—down.	Above—down.	Above—down.
Toronto	5.3 W.	+43.7	44	noon.	Above—down.	Above—up.	Above—down.
Washington ..	5.1 W.	+38.9	37	noon.	Above—up.	Above—up.	Below—up.
Greenwich	0.0	+51.5	33	noon.	Above—down.	Below—down.	Above—down.
Paris	0.2 E.	+48.8	24	mid.	Below—down.	Below—down.	Below—down.
Potsdam	0.9 E.	+52.9	49	noon.	Above—up.	Above—up.	Above—up.
Vienna	1.1 E.	+48.2	37	noon.	Above—up.	Below—up.	Above—up.
Powlowsk	2.0 E.	+59.7	36	mid.	Above—down.	Above—up.	Above—up.
Zi-ka-wei	8.1 E.	+31.2	37	6 p. m.	Below—up.	Above—up.	Below—up.
Melbourne	9.7 E.	—37.8	36	10 a. m.	Above—up.	Above—up.	Below—down.
Standard system			36	noon.	Above—up.	Above—up.	Above—up.

[1] Compare "The earth a magnetic shell." (Amer. Journ. Sci., Vol. L., August, 1895.)

Thus, in the Table 13 of the arrangement of the photographic traces, in the third space is given the length of the trace for a 24-hour run and the time of changing the sheets. When the traces are laid down so that the base line showing the time intervals increases from left to right, the trace is in some cases above and in others below the base line. The positive values of the ordinates increase sometimes up and sometimes down. They are not similarly disposed for each of the H. D. V. elements at the same station. The "Base line—Trace—Ordinates" show these differences at ten stations. It is suggested that the "standard system" indicated in the lowest line will satisfactorily take the place of the existing discordant systems, as a practical matter.

Table 14.

ORDINATES FOR THE DIURNAL VARIATIONS IN H. D. V.

[In millimeters.]

Hour.	San Antonio.			Toronto.			Washington.			Greenwich.			Paris.			Potsdam.			Vienna.			Pawlowsk.			Melbourne.		
	H.	D.	V.	H.	D.	V.	H.	D.	V.	H.	D.	V.	H.	D.	V.	H.	D.	V.	H.	D.	V.	H.	D.	V.	H.	D.	V.
Midnight	−0.7	−0.3	+0.4	0.0	−0.7	+0.1	0.0	−0.5	0.0	+1.2	−2.7	−0.4	+0.6	−1.2	0.0	+1.1	−2.0	+0.9	+1.5	−1.3	+0.3	+1.2	−1.5	−0.7	+0.7	+0.7	−1.3
1	−0.5	0.0	+0.3	0.0	−0.6	+0.2	−0.1	−0.3	+0.3	+1.1	−2.1	−0.5	+0.6	−1.0	−0.1	+1.0	−1.2	−0.5	+1.2	−1.1	0.0	+0.8	−1.2	−1.4	+0.7	+0.6	−1.5
2	−0.2	0.0	+0.3	+0.1	−0.6	+0.2	+0.3	−0.1	+0.2	+0.9	−1.8	−0.9	+0.6	−0.8	−0.1	+0.9	−1.0	−1.1	+1.2	−0.9	−0.2	+0.8	−1.1	−1.2	+0.8	+0.5	−1.4
3	−0.1	−0.1	+0.2	0.0	−0.8	+0.2	+0.4	−0.1	+0.1	+0.7	−1.9	−0.8	+0.6	−0.7	−0.2	+0.9	−0.8	−1.5	+1.0	−0.7	−0.2	+0.6	−1.1	−1.2	+0.8	+0.5	−1.6
4	+0.3	+0.1	+0.2	+0.2	−1.3	+0.2	+0.6	−0.3	+0.1	+0.6	−2.2	−0.3	+0.8	−0.7	−0.1	+1.0	−0.8	−1.0	+1.0	−0.6	−0.2	+0.8	−1.1	−1.1	+0.9	+0.5	−1.5
5	+0.7	0.0	0.0	+0.2	−2.3	+0.1	+0.8	−0.3	+0.2	+0.6	−2.7	+0.1	+0.6	−0.9	−0.1	+1.0	−1.1	−1.0	+1.2	−0.9	−0.2	+0.8	−1.1	−0.9	+1.0	+0.9	−1.6
6	+1.4	+0.1	+0.2	+0.3	−3.6	0.0	+1.2	−0.5	+0.2	+0.1	−3.2	+0.1	+0.5	−1.2	0.0	+0.8	−1.3	−0.6	+1.0	−1.0	−0.2	+0.8	−1.3	−0.7	+1.0	+1.0	−2.0
7	+2.4	−0.1	+0.3	+0.1	−4.8	+0.1	+1.5	−0.7	+0.3	−0.9	−3.4	+0.4	+0.1	−1.4	0.0	+0.2	−1.7	0.0	+0.2	−1.5	0.0	+0.2	−1.6	−0.5	+0.6	+3.8	−2.4
8	+2.0	−1.3	+0.3	−0.5	−5.2	+0.1	+1.2	−1.3	+0.2	−2.3	−3.7	−0.1	−0.5	−1.6	−0.1	−0.8	−2.0	+0.5	−1.0	−1.8	+0.3	−0.8	−1.7	−0.4	0.0	+5.2	−3.0
9	+1.6	−2.1	+0.3	−0.9	−4.3	+0.2	+0.6	−1.7	−0.1	−4.1	−2.9	−1.2	−1.2	−1.2	−0.5	−1.8	−1.6	−2.2	−2.2	−1.5	0.0	−2.0	−1.3	−0.4	−1.3	+5.7	−1.3
10	−1.0	−2.2	−0.1	−1.4	−1.4	+0.4	−0.2	−1.6	−0.5	−5.5	−0.2	−2.3	−1.8	0.0	−1.0	−2.6	−0.1	−6.6	−3.0	−0.2	−0.7	−3.0	−0.2	−0.4	−2.3	+4.0	−0.1
11	−3.2	−0.8	−1.3	−1.5	+2.0	+0.3	−1.4	−0.5	−0.8	−4.7	+3.8	−3.2	−1.6	+1.6	−1.4	−2.1	+1.9	−10.8	−2.2	+1.6	−1.5	−3.4	+1.4	−0.5	−2.6	+1.0	+1.4
Noon	−3.2	+0.8	−1.2	−1.1	+4.9	+0.2	−2.2	+1.0	−1.1	−3.2	+7.3	−3.5	−1.1	+2.8	−1.4	−1.6	+3.5	−11.4	−2.0	+3.1	−1.7	−3.0	+3.1	−0.4	−2.2	−2.2	+2.2
1	−0.9	+1.8	−0.9	−0.5	+6.2	0.0	−2.1	+2.0	−0.5	−1.2	+8.6	−2.2	−0.8	+3.4	−1.0	−0.9	+4.2	−8.1	−0.7	+3.8	−1.2	−2.2	+4.3	0.0	−1.4	−4.6	+2.8
2	+0.1	+1.8	−0.7	+0.2	+5.9	−0.1	−1.3	+2.3	−0.2	+0.2	+7.7	−0.3	−0.4	+3.1	−0.4	−0.5	+3.9	−3.3	−0.5	+3.6	−0.5	−1.0	+4.3	+0.5	−0.6	−5.9	+3.1
3	+0.8	+1.7	−0.4	+0.8	+4.5	−0.3	−0.6	+2.1	+0.1	+1.0	+5.5	+1.3	−0.1	+2.2	+0.3	−0.3	+2.6	+2.3	−0.5	+2.4	+0.3	−0.2	+3.4	+1.2	+0.1	−5.3	+2.7
4	+1.4	+0.9	−0.1	+1.0	+3.0	−0.4	+0.1	+1.5	+0.2	+1.2	+3.3	+2.3	−0.1	+1.2	+0.6	−0.3	+1.8	+4.8	−0.5	+1.3	+0.7	+0.2	+1.9	+1.8	+0.4	−3.9	+2.4
5	+0.8	+0.5	+0.2	+0.9	+1.6	−0.4	+0.4	+1.0	+0.2	+1.6	+1.4	+2.8	+0.1	+0.4	+0.9	−0.1	+0.4	+6.5	−0.5	+0.3	+0.8	+0.6	+0.9	+1.8	+0.4	−2.2	+1.7
6	+0.3	+0.3	+0.2	+0.7	+0.6	−0.4	+0.7	+0.6	+0.1	+2.2	+0.1	+2.7	+0.4	0.0	+0.9	+0.2	−0.1	+6.5	−0.2	−0.1	+0.8	+0.8	0.0	+1.8	+0.4	−1.1	+1.5
7	−0.7	0.0	+0.4	+0.5	+0.1	−0.3	+0.2	0.0	+0.2	+2.6	−1.0	+2.3	+0.5	−0.5	+0.8	+0.6	−0.6	+5.7	+0.5	−0.4	+0.7	+1.2	−0.5	+1.6	+0.4	−0.5	+1.3
8	−1.1	−0.3	+0.4	+0.3	+0.3	−0.3	0.0	−0.3	+0.3	+2.4	−1.9	+1.9	+0.6	−0.6	+0.6	+0.9	−0.9	+4.8	+1.0	−0.9	+0.7	+1.4	−0.9	+1.2	+0.5	−0.4	+0.3
9	−0.2	−0.3	+0.4	+0.2	−0.6	−0.2	−0.1	−0.6	+0.3	+2.2	−2.5	+1.3	+0.8	−0.9	+0.5	+1.0	−1.1	+4.4	+1.0	−0.9	+0.7	+1.6	−1.4	+0.7	+0.6	−0.1	−0.3
10	−0.6	−0.4	+0.5	+0.2	−0.8	−0.1	0.0	−0.7	+0.3	+1.6	−2.8	+0.5	+0.8	−1.3	+0.4	+1.2	−1.5	+3.9	+1.5	−1.2	+0.7	+1.2	−7.6	0.0	+0.6	+0.3	−0.4
11	−0.3	−0.1	+0.4	+0.1	−0.8	0.0	0.0	−0.8	+0.2	+1.5	−3.0	−0.1	+0.6	−1.2	+0.1	+1.0	−1.5	+2.0	+1.5	−1.4	+0.5	+1.4	−1.6	−0.4	+0.6	+0.6	−1.0
Midnight	−0.7	−0.3	+0.4	0.0	−0.7	+0.1	0.0	−0.5	0.0	+1.2	−2.7	−0.4	+0.6	−1.2	0.0	+1.1	−2.0	+0.9	+1.5	−1.3	+0.3	+1.2	−1.5	−0.7	+0.7	+0.7	−1.3

Mean ordinates from the base line to the middle line of the scale.

Jan. 4	18	48	20	56	46	35	32	42	51	45	38	68	12	13	16	15	64	22	63	33	77	35	35	44	9	73	38
Jan. 28	19	48	21	56	46	34	32	43	51	37	36	73	14	12	16	15	63	47	61	33	78	34	34	44	8	73	40
Feb. 13	19	48	22	56	47	34	0	C	0	39	36	73	13	12	14	15	63	63	62	34	81	24	3	5	37	73	40

Equivalents of 1 millimeter in units fifth decimal, C. G. S.

Jan. 4	4.5	9.8	10.0	10.0	4.0	16.4	4.5	6.6	8.2	2.9	2.6	2.6	7.6	8.7	9.3	5.2	6.0	1.0	4.1	6.7	6.2	5.3	4.6	5.9	10.0	7.9	7.5
Jan. 28	4.5	9.8	10.0	10.0	4.0	16.4	4.5	6.6	8.2	2.9	2.6	2.6	7.6	8.7	9.3	5.2	6.0	1.0	4.1	6.7	6.2	5.3	4.6	5.9	10.0	7.9	7.5
Feb. 13	4.5	9.8	10.0	10.0	4.0	16.4	12.0	19.2	13.3	2.9	2.6	2.6	7.6	8.7	9.3	5.2	6.0	1.0	4.1	6.7	6.2	5.3	4.6	5.9	10.0	7.9	7.5

PROCESS FOR ELIMINATING THE TRUE DISTURBANCE ORDINATES.

In order to get the pure ordinates belonging to the disturbance force proper, which is conceived to be superposed upon the mean diurnal variation at any instant of time, the following process was employed: From the records of each observatory, construct the mean diurnal trace of each element in millimeters; plot on a strip of semitransparent celluloid a scale having the length of the trace, with dots showing the mean position of H. D. V. at each hour. Such variations in millimeters are given in Table 14 for nine stations. Zi-ka-wei is omitted because its traces for February 13 were not at hand; those for January 4, January 28 were worked up with the others. These are normal variations so long as scales and sensitiveness remain unchanged. The mean ordinates from the base line to the zero line of the scale was computed, and they are given in the same table. These values enable us to place the long scale upon the disturbed trace at the mean distance for the day, and then the ordinates between the scale points and the trace itself, at the selected instant, give the values $\triangle$ H, $\triangle$ D, $\triangle$ V in millimeters, from which data the computation proceeds as before to σ, s, α, β. The distance from the base line to the zero line of the scale was determined from the position of the traces on the days just preceding and following the disturbance. The equivalents of 1 mm. in units fifth decimal C. G. S. are given at the bottom of the table. Next, certain hours and minutes were selected on the Greenwich traces for computation of the impulses, and the corresponding instants found on all the other traces, by allowing for the longitude corrections. The results σ, s, β for February 13, 1892, from 6.30 a. m. to 11.26 p. m., G. M. T., are transcribed in the accompanying Table 15.

Table 15.—*Deflecting forces during the great disturbance February 13, 1892, at nine widely separated stations.*

[Units fifth decimal.]

Hour. G.M.T.	Horizontal component σ.									
	S. A.	T.	W.	G.	P_a.	P_o.	V.	P_w.	M.	Mean.
h m										
6 30...	66	53	140	26	57	33	.....	67	111	69
7 45...	27	54	39	46	36	55	.....	64	171	62
7 55...	34	104	14	73	87	60	.....	70	180	78
8 07...	51	23	0	70	24	47	.....	34	144	49
8 30...	53	20	90	33	97	88	.....	54	96	66
8 40...	29	32	82	91	13	26	.....	38	115	53
8 50...	55	30	40	29	114	91	.....	120	80	70
9 25...	17	32	27	144	102	26	.....	15	127	61
9 50...	76	163	46	.....	87	111	.....	160	124	110
10 12...	63	111	80	81	28	55	.....	49	87	69
10 30...	52	162	40	93	83	78	.....	130	131	96
10 55...	144	332	163	78	26	92	.....	95	61	124
11 05...	150	175	75	138	106	66	.....	98	85	112
12 00...	156	234	145	112	98	80	.....	59	38	115
1 00...	148	595	312	122	126	133	.....	388	75	237
1 45...	214	610	280	36	58	32	77	388	97	199
2 08...	210	400	330	73	102	94	120	388	133	205
3 00...	225	330	268	17	69	.....	143	392	106	194
3 20...	240	350	252	103	23	26	120	388	126	181
3 40...	.....	400	300	182	107	156	134	374	164	227
4 25...	270	404	362	164	138	33	197	270	194	226
4 35...	283	374	366	146	46	180	88	374	209	230
5 20...	266	302	386	266	201	172	37	74	179	209
6 00...	288	164	372	165	164	144	112	23	220	184
6 25...	286	196	205	147	99	85	103	175	138	159
6 53...	302	318	234	130	29	51	103	101	174	160
7 10...	254	350	232	82	36	63	146	234	141	171
7 19...	306	318	162	58	47	47	166	340	162	178
7 38...	296	461	173	160	53	.....	199	53	148	193
8 30...	308	750	126	127	150	210	268	455	262	295
9 25...	276	850	246	130	143	157	220	776	338	348
9 55...	262	730	64	308	340	360	334	865	336	400
10 26...	280	290	124	177	205	236	274	342	316	249
10 52...	260	57	77	132	122	153	186	292	330	178
11 26...	244	73	81	179	130	179	204	378	294	196

Hour. G.M.T.	Total deflecting force s.									
	S. A.	T.	W.	G.	P_a.	P_o.	V.	P_w.	M.	Mean.
h m										
6 30...	78	112	144	28	58	33	.....	67	111	79
7 45...	40	157	66	50	40	55	.....	64	172	81
7 55...	43	182	55	75	87	60	.....	70	180	94
8 07...	53	55	53	73	32	47	.....	35	144	62
8 30...	63	101	160	33	99	88	.....	54	100	87
8 40...	45	88	134	91	29	28	.....	38	117	71
8 50...	59	87	77	34	114	91	.....	120	82	83
9 25...	27	46	48	144	103	27	.....	17	127	67
9 50...	80	366	56	.....	87	111	.....	162	124	141
10 12...	68	286	133	81	31	60	.....	58	89	101
10 30...	54	366	120	94	83	79	.....	136	133	133
10 55...	153	394	204	87	64	100	.....	112	61	147
11 05...	153	402	153	140	116	73	.....	118	90	156
12 00...	161	378	212	113	109	23	.....	121	48	146
1 00...	156	800	.....	134	152	147	.....	486	78	279
1 45...	222	680	.....	160	169	106	96	560	100	262
2 08...	218	432	.....	209	197	.....	142	540	134	268
3 00...	230	336	.....	222	234	.....	170	590	107	270
3 20...	246	350	.....	256	252	.....	156	590	130	283
3 40...	.....	416	.....	296	284	.....	167	550	165	313
4 25...	274	436	.....	276	352	.....	220	470	195	318
4 35...	286	450	.....	266	328	.....	128	470	210	305
5 20...	268	590	.....	346	380	.....	100	165	180	290
6 00...	288	628	.....	288	364	.....	142	131	224	295
6 25...	286	730	.....	276	338	.....	131	202	144	301
6 53...	302	880	.....	268	234	.....	123	156	182	306
7 10...	260	800	.....	282	228	.....	156	338	151	316
7 19...	306	760	.....	216	220	.....	176	189	176	292
7 38...	296	830	.....	252	392	.....	209	130	166	325
8 30...	308	840	.....	220	232	234	274	465	276	356
9 25...	276	950	.....	204	200	172	224	825	352	400
9 55...	262	880	.....	332	350	364	340	930	350	476
10 26...	280	500	.....	179	236	236	276	450	328	311
10 52...	260	381	.....	144	166	160	191	390	340	254
11 26...	244	420	.....	187	160	180	205	590	300	286

Hour. G.M.T.	Azimuth angle β.									
	S. A.	T.	W.	G.	P_a.	P_o.	V.	P_w.	M.	Mean.
h m										
6 30...	17	101	21	100	36	99	.....	187	8	70
7 45...	180	158	98	221	280	280	.....	300	355	234
7 55...	144	164	135	270	321	330	.....	327	360	256
8 07...	29	154	360	209	227	230	.....	222	327	219
8 30...	197	180	107	329	326	317	.....	355	264	259
8 40...	201	232	360	244	307	354	.....	278	322	262
8 50...	169	173	225	342	317	313	.....	303	354	275
9 25...	116	320	313	228	297	349	.....	289	342	282
9 50...	184	157	122	.....	244	327	.....	355	334	246
10 12...	204	206	133	.....	262	259	.....	319	314	242
10 30...	161	137	286	.....	322	322	.....	325	314	267
10 55...	205	184	144	149	90	148	.....	177	8	136
11 05...	187	138	195	214	222	124	.....	303	34	177
12 00...	203	168	184	196	196	193	.....	316	302	220
1 00...	168	164	144	279	242	296	.....	356	57	213
1 45...	168	171	170	256	205	324	256	356	214	236
2 08...	164	177	170	233	224	236	207	357	138	212
3 00...	177	177	172	229	187	.....	199	9	197	168
3 20...	185	178	177	345	260	292	196	357	62	228
3 40...	.....	177	180	353	335	230	214	354	192	254
4 25...	182	186	183	304	248	160	228	333	136	218
4 35...	183	189	189	302	300	284	213	357	140	240
5 20...	186	214	201	13	309	4	133	136	142	149
6 00...	182	245	195	283	293	252	196	270	117	226
6 25...	185	273	208	323	280	266	156	148	136	219
6 53...	192	281	215	360	31	108	162	114	129	177
7 10...	194	321	261	264	228	222	197	163	142	221
7 19...	189	319	253	360	107	180	154	170	172	211
7 38...	190	325	232	103	138	.....	162	120	144	177
8 30...	192	339	247	157	164	172	173	187	173	200
9 25...	193	353	332	218	205	187	187	187	204	230
9 55...	191	345	293	152	212	171	170	197	189	213
10 26...	194	326	321	171	179	202	193	210	203	222
10 52...	188	330	202	190	185	207	186	186	212	210
11 26...	187	326	208	153	207	187	189	197	191	205

An inspection of the numbers shows the increase of the disturbance up to its maximum values of σ, s; at the same time the large majority of the values of β are directed approximately southward, especially when the disturbance strengthens at all the stations. Toronto and Pawlowsk show unusually large values of the σ s at certain hours, and this may be due to some peculiar action of their magnets, or to excessive concentration of the external field at these localities. It is of course not my purpose to examine the records of the several stations, except as they compare with one another in a general way. The conclusion arrived at is that the disturbance impulses indicate an unusual strengthening of the impressed field; and that the great vector impulses are directed southward.

TABLE 16.

MEAN VALUES OF s, α, β.

Date	Jan. 4.	Jan. 29.	Feb. 13.
	°	°	°
North group	349 12	341 14	321 15
South group	187 50	171 30	195 73
Mean s	0. 00053	0. 00040	0. 00166
Computed α	33. 5°	36. 6°	39. 7°
Observed α	22. 7°	23. 5°	27. 9°

The mean values of s, α, β, for the three disturbances of January 4, January 29, February 13, each taken as a whole, are collected in the Table 16, which contains the angle β in the north and south groups, the number of distinct impulses measured on the trace, the mean s, the mean computed and observed values of α. These are not the maximum but the average values of the disturbing vectors throughout the entire disturbance, the time extending to the hours of the quiet fields. The maximum values of s for February 13 is about thirty times that of the average European field and is directed southward. In almost all cases on other dates the large vectors point in the same direction. After examining all the disturbances whose records are accessible, from 1841 to 1896, inclusive, it may be laid down as a rule that the disturbances of pronounced type are always impressed upon the earth's normal field from north to south.

A complete computation of all the large and small disturbances for Washington, 1889, 1890, 1891, taking out the disturbing vectors for every half hour during the period of deflection, shows a ratio of three to one in the south quadrant over the north, east, or west quadrants. It is not easy to see how anything is lacking to verify this fact that *great disturbances are impressed southward upon the earth's field.* Also the angles α are such that lines of impressed force cut across the normal magnetic lines derived from the earth's internal magnetization, and therefore they must be propagated from outside of the earth's surface.

COMPONENTS OF THE LINES OF A SPHERICAL MAGNET IN A UNIFORM FIELD.

It is desirable to have clearly in mind what the effect is upon the lines of the normal field of a magnetized sphere immersed in a uniform field when the latter becomes stronger or weaker. Compare charts 6, 7, 8. Let A B, chart 12, be part of the normal field, however generated; let A D be lines in the impressed field, when pointing southward on the right side, and northward on the left side of the diagram, which thus

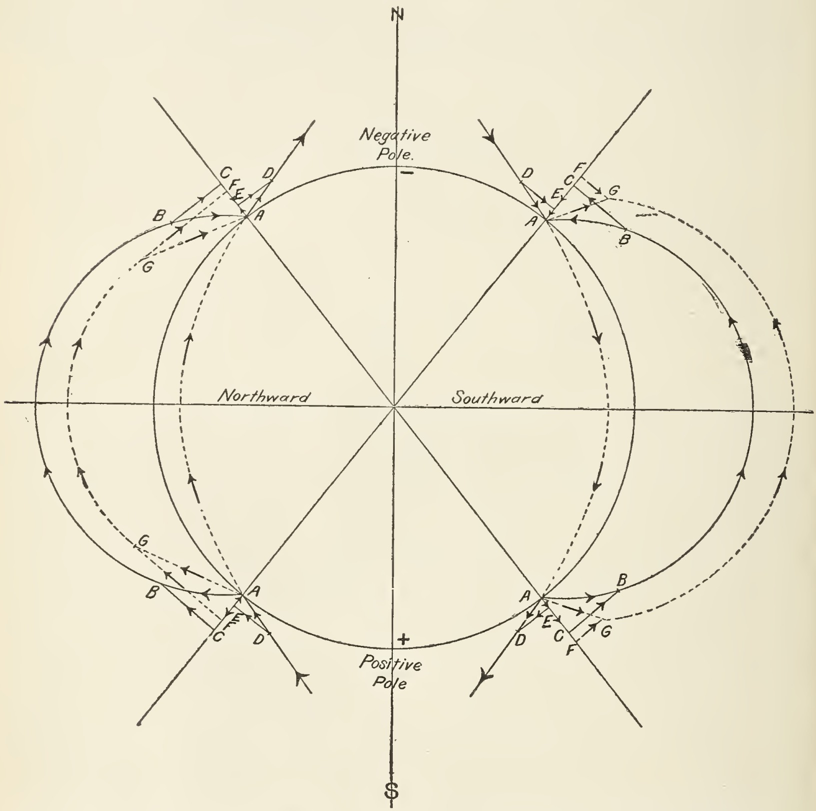


CHART 12.—Components of the impressed forces disturbing the earth's normal field in both north and south directions.

includes the case of an oscillation to each side of the mean value of the normal terrestrial and external fields. Resolve along radii of the sphere extended. The components of A B are, A C on radius, B C perpendicular to it; those of A D are A E and E D; the vector sum of these components in each case is A G, which is a part of the resultant line of the compound field. On the right the new magnetic line is outside the original normal position, and on the left it is inside the same. An alternating impressed external field therefore expands the lines of the entire magnetic field outward or contracts them inward, thus increasing

or decreasing the stability of the sphere as a magnet. Such alternations occur irregularly in disturbances, as the traces show; they may occur periodically, with a wave-like vibration of the system. Dr. Eschenhagen's observations on the minute variations of the terrestrial field, with waves of fifteen seconds or some other short period, seem to indicate that such pulsations pertain to the earth's field as one of its permanent characteristics. Variations of the magnetic field must be accompanied by electric currents, which may profoundly affect the state of the atmospheric electric field by integration. Half of the energy of the impressed magnetic field must be expended in the system somewhere as heat, and the other half in making magnetic potential.[1]

CRITICISM OF OTHER THEORIES TO ACCOUNT FOR THE VARIATIONS IN THE EARTH'S MAGNETIC FIELD.

It may be observed that if any one seeks to account for the existing magnetic field by putting the electric currents first in time as the cause of magnetic changes, then the electric system must oscillate, as the magnetic field requires. If it is attempted to account for the electric currents as convection electricity transported in the meteorological currents of atmospheric circulation, then not only must the meteorological currents oscillate back and forth, to accord with the electro-magnetic system, but they must do so simultaneously over the entire earth, because the magnetic variations are synchronous over the globe at the same instant. Since there is no evidence that this meteorological fact exists, it is inferred that the extra terrestrial seat of the magnetic field is pulsating in wave-like oscillations. Thus the magnetization of the sun may be supposed to vary its magnetization periodically or spasmodically; then these variations of energy are propagated in transient magnetic currents to the earth's field, where the pulsations are taken up and exhibited by the observed changes in H. D. V.

It may also be noted that the normal field of the earth is also a compound field. If the earth's magnetic field has a true potential, it is also plunged within an external field, assumed to be steady for the instant. What we observe as normal is the resultant of these two fields. Such an internal field would therefore have impressed upon it an external field, distributed in magnetic latitude as chart 11 indicates. Hence the Gaussian potential system may not be able by expanding terms of the harmonic orders to account entirely for the observed surface field. Indeed, it is concluded from the analysis of observations that such an external field must exist, in addition to the simple potential field, even with a heterogeneous disposition of the internal magnetization of the earth.

It may be noted that a system of vertical earth-air electric currents, such as L. A. Bauer describes (Terrestrial Magnetism, II, 1, p. 18), conforms to the scheme of Chart 11, if the Bauer curve is inverted, and the

[1] Compare Heaviside, Physical Papers, vol. 1, pp. 456, 462.

earth rotates its field through an external field, whose strength is distributed in latitudes according to the results of this discussion.

Since the observed "disturbances" of the external field are about a mean value $[F_1+F_2+\Delta(F_1+F_2)]$, where F_1 is the normal force of the internal and F_2 the external fields, and $\Delta(F_1+F_2)$ the variations on the resultant of F_1+F_2, it is evident that the determination of F_2 is involved in the computation of the intensity of solar magnetization itself. That part of the problem is therefore properly in the hands of the students of the earth's potential system.

The fact seems to be clear that the earth's normal field is constantly penetrated with an external field, which also traverses the outer parts of the earth's body. The interaction of the two fields, together with the induction due to rotation of the earth on its axis within the external field, may be presumed to integrate in long periods of time into such changes as are observed in the secular variations of the station elements. The fact that a general tendency exists to follow one direction of rotation, namely, from east to west, or clockwise, is evidence in favor of this view. This problem, however, as well as that of the atmospheric electricity, is at present nearly indeterminate, because the underlying vector system can not be completely computed from existing observations, since the earlier records give only the directional elements, declination and inclination; the strength of the vector, the magnetic intensity, not having been measured previously to 1830. Sufficient time has not yet elapsed to produce a picture of the secular variation of the impressed disturbing vectors. However, good work is being done in collating all the ancient material regarding the elements of direction of the normal field at as many epochs as possible. Compare the papers of Schott, Littlehales, Bauer, and Putnam.

Chapter 4.

DEFLECTING FORCES OF THE EQUATORIAL ELECTRO-MAGNETIC FIELD.

Before proceeding to develop the other physical effects of the action of the "coronal" or polar-magnetic field within the earth's magnetic field and the atmosphere, it will be expedient to discuss the second external magnetic field in which the earth is supposed to be immersed. This is called the "radiant" or electro-magnetic field, and its axis at the earth is parallel to the plane of the ecliptic, being the radius vector drawn from the sun to the earth. The electro-magnetic theory of light implies the existence of a magnetic field practically uniform in force and direction, relatively to any magnet large in comparison with the wave lengths of light, and hence to any magnet except of atomic and molecular dimensions. The sun throws out spherical electro-magnetic induction sheets, which the ether transmits to the spaces penetrated by sunlight. These are composed of rapidly alternating waves of electric force and magnetic induction arranged in quadrature to each other. The vibration is so rapid that the train of individual waves merges into a steady field in its action upon the earth as a magnet, or to the exploring magnets employed in observations. It is found from observations that the lines of the normal magnetic terrestrial field suffer such distortion as would occur if a magnetized sphere surrounded by a shell of low permeability were placed in an external field with its axis approximately at right angles to the direction of the field. The physics arising from this conception in the case of the earth, which is continually changing the aspect of the axes of the sphere and of the magnetic field, becomes very complex in details, and it is not my purpose in this abstract to pursue these questions beyond the introductory stages. The data must be discussed with much precision for the consideration of the delicate problems implied in these relations.

DETERMINATION OF THE VECTORS OF THE ELECTRO-MAGNETIC SYSTEM.

The process of obtaining the vectors of the deflecting forces of the electro-magnetic field is simpler than in the case of the polar-magnetic field, but the resulting system is much more complex and difficult to present intelligibly without the use of a globe model. Indeed, it is quite impossible to study the problem satisfactorily except by transferring the computed vectors to a sphere, in which case the apparent tangle

of forces displays a beautifully balanced symmetry. It is, therefore, believed that the labor of making such a model will repay each student of terrestrial magnetism. In computing the vectors of the polar field the data was obtained by taking the variations of the daily means on a slowly changing normal field derived from the means of the months—that is to say, dealing with the right-hand column of means as usually published. The vectors of the electro-magnetic field are, on the other hand, found by computing the variations of the hourly means for each month relatively to the mean of the month—that is, by simply subtracting the monthly mean along the lowest row of the page as commonly printed. There is obviously no need to make any secular changes in these quantities, because the 24-hourly means are in every case simultaneously synchronous throughout the day. The diurnal variations of the needle at any station are caused by the earth in its rotation transporting this station to the successive 24 points in the impressed field where the observations are made. Since the aspect of the sunlight field is similar once in twenty-four hours for every station on the earth, the record of stations widely separated in longitude may be made to begin on one meridian by ignoring the variations in local time, though, of course, in fact, each station is at the same moment experiencing the deflection due to that part of the field in which it then happens to be placed. The earth may thus be studied as a nonrotating body relatively to the external field by simply orienting the vectors of each station from that meridian whose plane when extended will pass through the center of the sun. By computing the vectors for each month and the mean of these for the twelve months, a mean vector system will be found with the sun in the equatorial plane. The intersection of the central meridian and the equatorial planes locates the direction of the axis of the external field before any distortion caused by the immersed earth takes place in it. The solar field has an outward diminution in induction, and hence a force directed from the sun into space. Such a magnet as the earth placed in an external field should experience deflections after the nature of couples, directed toward the sun in the northern hemisphere and from the sun in the southern hemisphere, with very well defined distribution of the forces in sheets, determined by the aspect of the curvature of the shell in the several latitudes relatively to the direction of the field. It has not yet been practicable for me to give the work necessary to elaborate analytically the magnetic fields produced under these conditions, because of the difficulties arising from the peculiar asymmetric distortion due to the lag of rotation and the temperature distribution in latitude and longitude as the result of solar radiation upon the tropics. The following scheme (chart 13), however, gives some idea of the relations that appear to exist:

CHART 13.—Schematic distribution of the disturbing vectors of a magnetized sphere, covered by a permeable shell, immersed in an external magnetic field and at right angles to it.

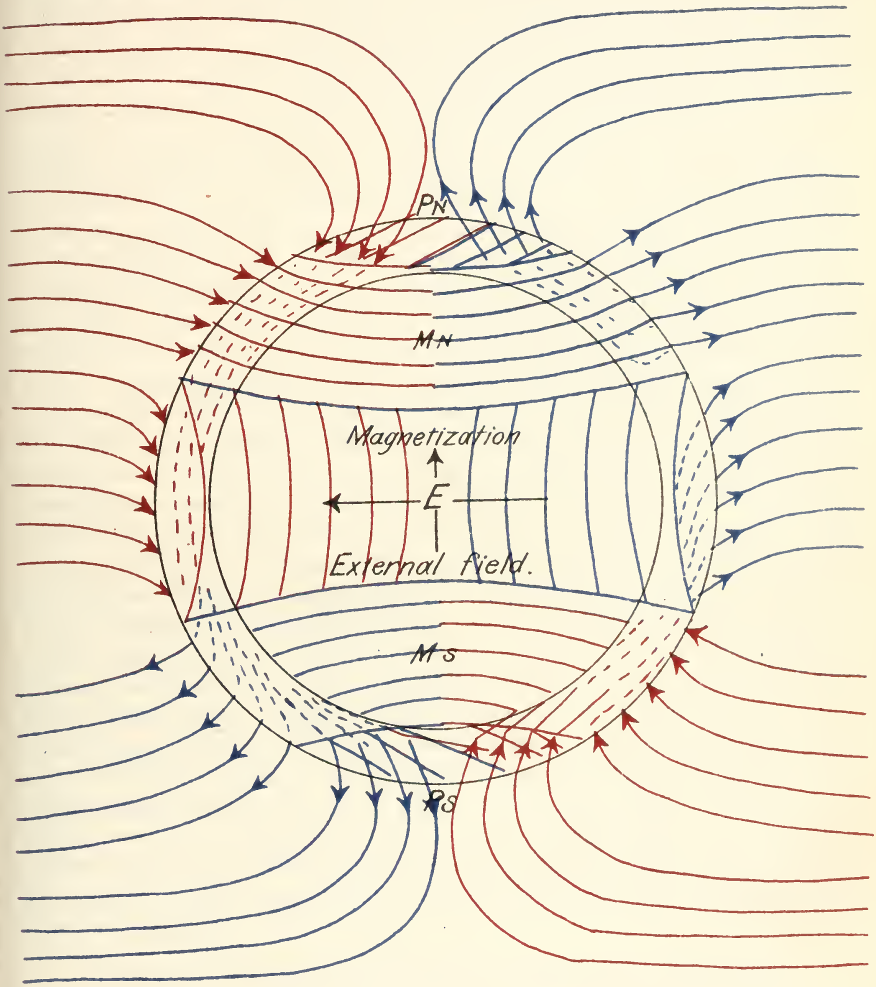


Chart 13.

A PERMÉABLE SHELL INCLOSING A SPHERE MAGNETIZED AT RIGHT ANGLES TO AN EXTERNAL FIELD.

The shell may be divided into two polar caps, P_n and P_s, cut off by planes perpendicular to the axis of magnetization and nearly touching the impermeable nucleus; into two midlatitude zones M_n and M_s, having sphero-conical surfaces; and into one equatorial sphero-rectangular zone E, parallel to the axis of magnetization. If the sun lies in the plane of the diagram central to the right, its field is directed from right to left. The earth is a magnet, with its external field directed in wide curves upward. Every unit volume of the new compound magnetic field is the resultant of these two fields, now excluding the coronal field. The observations are made at the surface of the earth for the deflections, and the field can not be explored outwards, except analytically, or by model-magnets. The deflecting forces are arranged along lines which seek the path of least magnetic resistance, and that is through the shell. Each polar cap has a twisting couple, the components acting against one another in the opposite hemispheres and penetrating the shell. The midlatitude zones constitute also a couple, acting to the right in the northern zone and to the left in the southern, penetrating the shell about parallel to the ecliptic. The equatorial zone contains a couple, on the right side upward and on the left side downward, penetrating the shell merely at right angles to the plane of the orbit. These may merge into discontinuous sheets to form one system. The effective magnetic forces are the physical resultants of an extremely rapid alternating field acting upon the earth's magnetic field. Induction is probably important, as shown by the greatly increasing strength of the deflecting field in the polar caps. The temperature is also an efficient term, because magnetic effects increase with decrease of the temperature of the medium. The rotating of the earth is a term of some importance and may partly account for the lag, though this view is contradicted by the peculiar twist in the polar caps, where the axis of the couple is nearly at right angles to that of the couples in the middle zones. Convection currents of the atmospheric circulation, static atmospheric electricity, the disintegration of the radiant waves into heat, are also elements to be considered in the solution of this complex problem.

COMPUTATION OF THE VECTOR SYSTEM FOR JAN MAYEN.

The preceding remarks are based upon the results of the following computation: There are 30 stations available for the discussion of observations in H. D. V. during a year, from which the simultaneous variations $\triangle$H. $\triangle$D. $\triangle$V. can be obtained. Table 17 gives the stations, their geographical position, the year of the record, and the magnetic elements in the two systems, F. D. I. and H. D. V.

TABLE 17.—*Coordinates of the magnetic elements at thirty stations.*

Stations.	Longitude.	Latitude.	Year.	Declination.	Inclination.	Mag. Lat.	Horizontal force.	Vertical force.	Total force.
	h m s	° ′ ″		° ′	° ′	° ′			
Kingua Fjord .	4 29 21 W	+66 35 40	1882–1883	72 12 W	83 52	77 52	0.06379	0.59321	0.59662
Fort Rae	7 42 55 W	+62 38 52	1882–1883	40 20 E	82 55	76 2	0.07669	0.61760	0.62234
Uglaamie......	10 26 30 W	+71 17 42	1882–1883	35 37 E	81 23	73 8	0.08940	0.58980	0.59652
Cap Thordsen.	—1 2 49 E	+78 28 27	1882–1883	12 49 W	80 27	71 4	0.08921	0.53006	0.53751
Jan Mayen....	0 33 53 W	+70 59 48	1882–1883	29 53 W	79 2	68 49	0.09745	0.50294	0.51229
Bossekop......	—1 35 59 E	+69 57 29	1882–1883	4 3 W	76 32	64 25	0.12087	0.50456	0.51885
Toronto.......	5 17 33 W	+43 39 24	1843–1848	1 29 W	75 15	62 14	0.16325	0.62000	0.64121
Sodankyla	—1 46 25 E	+67 24 30	1882–1883	1 20 W	74 45	61 24	0.13352	0.49095	0.50781
Makerstown ..	0 10 4 W	+55 34 45	1845	25 11 W	71 15	55 50	0.15603	0.45963	0.48540
Washington ..	5 8 12 W	+38 53 39	1890	4 6 W	71 5	55 34	0.19860	0.57928	0.61238
Pawlowsk.....	—2 1 56 E	+59 41 00	1883	0 42 W	70 44	55 3	0.16380	0.46858	0.49638
Dublin........	0 25 4 W	+53 21 00	1842–1843	27 17 W	70 41	54 58	0.16182	0.46166	0.48919
Wilhelmshaven	—0 32 35 E	+53 31 52	1882–1883	13 54 W	68 1	51 5	0.17773	0.44030	0.47483
Greenwich	0 0 0	+51 28 38	1883	18 15 W	67 32	50 24	0.18100	0.43762	0.47359
Parc Ste.Maur.	—0 9 23 E	+48 48 34	1889	15 45 W	65 13	47 17	0.19522	0.42269	0.46559
Vienna........	—1 5 28 E	+48 14 00	1884	9 35 W	63 24	44 47	0.20554	0.41031	0.45885
Pola..........	—0 55 24 E	+44 52 00	1890	10 14 W	60 43	41 43	0.21948	0.39127	0.44863
Los Angeles ..	+7 53 2 W	+34 2 58	1882–1889	14 28 E	59 30	40 20	0.27273	0.46300	0.53730
Tiflis.........	—2 59 10 E	+41 43 8	1883	0 59 E	55 35	36 7	0.25742	0.37566	0.45560
Zi-Ka-Wei	—8 5 45 E	+31 12 30	1885	2 9 W	46 18	27 37	0.32911	0.34435	0.47633
Bombay.......	—4 51 16 E	+18 53 30	1863	0 34 E	19 13	9 53	0.37187	0.12967	0.38969
Madras	—5 20 59 E	+13 4 8	1851–1855	1 0 E	7 37	3 50	0.37383	0.05015	0.37718
Singapore.....	—6 55 23 E	+ 1 17 0	1843–1845	1 35 E	—12 41	— 6 25	0.37250	—0.08383	0.38182
St. Helena.....	0 22 42 W	—15 56 41	1841–1845	22 46 W	—21 37	—11 12	0.25710	—0.10188	0.27655
Batavia	—7 7 14 E	— 6 11 0	1888	1 47 E	—28 25	—15 8	0.37094	—0.20070	0.42175
Süd Georgien..	2 24 0 W	—54 51 0	1882–1883	0 15 W	—48 53	—29 48	0.25668	—0.29405	0.39033
Cape Horn	4 41 41 W	—55 31 24	1882–1883	20 11 E	—52 55	—33 29	0.28536	—0.37760	0.47329
Cape Good Hope........	—1 15 55 E	—33 56 0	1841–1846	29 7 W	—53 21	—33 54	0.20740	—0.27876	0.34745
Melbourne	—9 39 53 E	—37 48 35	1858–1863	8 28 E	—67 20	—50 8	0.23567	—0.56409	0.61134
Hobarton	—9 49 50 E	—42 52 30	1841–1848	9 47 E	—70 36	—54 50	0.20700	—0.58790	0.62319

The station Jan Mayen, 1882, 1883, is transcribed in detail for every month except August, when there were no observations. The monthly mean is subtracted from the successive hourly means for $\triangle$ H. $\triangle$ D. $\triangle$ V, and these are transformed into σ, s, α, β. The annual means are taken and placed in the last column of Table 18.

TABLE 18.—*Diurnal deflecting forces at Jan Mayen, 1882–1883.*

Hour.	January.				February.				March.				April.			
	σ	s	α	β	σ	s	α	β	σ	s	α	β	σ	s	α	β
Mid.	45	53	+33	172	54	80	+48	195	27	71	+68	195	44	76	+55	195
1	58	70	+37	188	49	83	+55	202	30	73	+65	222	35	65	+57	215
2	38	60	+50	206	70	103	+48	132	76	102	+41	208	53	54	+44	220
3	30	40	+42	225	60	68	+40	227	100	125	+37	213	62	68	+37	223
4	35	53	+40	222	60	72	+34	232	100	118	+32	217	72	77	+22	224
5	45	46	+10	208	60	63	+18	238	90	95	+18	214	78	78	+ 5	226
6	22	22	— 8	234	30	30	— 2	272	65	65	+ 5	205	82	85	—13	230
7	16	20	—33	320	25	27	—18	280	50	57	—30	214	46	53	—30	222
8	20	22	—23	358	27	32	—33	330	13	57	—28	228	23	30	—40	236
9	22	22	— 6	2	28	30	—17	345	13	20	—48	235	20	22	—18	259
10	25	26	+15	2	25	25	— 4	347	61	63	—13	2	9	11	—40	75
11	32	33	+17	5	40	40	— 4	358	42	46	—24	2	16	16	—10	20
Noon.	45	46	+13	9	55	57	—18	3	60	67	—25	12	41	41	—14	8
1	46	46	+ 6	9	73	74	— 8	10	70	78	—26	20	73	74	— 8	9
2	48	48	— 1	12	80	84	—18	9	102	108	—22	15	83	84	— 8	12
3	62	63	—12	2	52	58	—22	15	92	102	—25	16	87	91	—18	16
4	51	55	—20	10	32	53	—53	35	105	120	—28	14	92	100	—25	20
5	45	52	—39	10	22	58	—67	45	81	99	—34	25	87	97	—26	20
6	11	40	—74	16	54	80	—48	66	40	66	—51	60	70	84	—34	54
7	40	65	—54	144	37	56	—49	100	38	64	—54	88	54	74	—44	71
8	33	50	—50	143	33	41	—50	88	51	53	—15	112	57	66	—30	89
9	46	50	—22	158	80	80	— 2	140	46	46	0	148	35	36	+17	110
10	30	31	+16	144	53	57	+20	142	40	50	+36	143	62	70	+27	178
11	40	45	+30	170	13	32	+64	200	46	75	+52	183	76	100	+38	174
Mid.	45	53	+33	172	54	80	+48	196	27	71	68	195	44	76	+55	195

TABLE 18.—*Diurnal deflecting forces at Jan Mayen, 1882–1883*—Continued.

Hour.	May.				June.				July.				September.			
	σ	s	α	β	σ	s	α	β	σ	s	α	β	σ	s	α	β
Mid.	84	98	+30	193	63	64	+12	175	46	78	+53	185	28	40	+44	187
1	77	97	+38	189	61	67	+26	200	97	130	+42	200	44	60	+42	206
2	75	100	+41	209	105	112	+32	195	100	145	+46	204	58	65	+28	214
3	93	105	+28	213	125	127	+11	207	140	171	+35	198	100	110	+24	200
4	100	104	+15	216	127	130	—11	210	104	127	+34	210	61	61	+ 5	211
5	92	92	— 2	214	128	140	—22	212	100	109	+23	215	56	57	—13	214
6	72	75	—16	215	94	116	—37	220	76	76	+ 1	222	48	56	—29	200
7	41	45	—24	222	46	90	—59	227	70	70	0	228	15	30	—61	182
8	29	33	—28	230	34	68	—70	233	60	61	— 7	218	15	25	—54	238
9	12	17	—46	230	16	70	—74	235	33	35	—19	210	9	13	—46	352
10	8	15	—56	125	16	55	—71	270	9	11	—43	270	6	7	—30	0
11	18	18	+89	8	29	70	—65	347	25	25	—10	348	30	30	— 1	22
Noon.	44	45	+14	17	46	80	—54	3	29	32	—26	8	60	61	+ 8	12
1	77	77	0	10	62	73	—58	358	86	90	—15	4	42	43	+12	30
2	94	94	— 3	8	97	130	—41	13	88	98	—25	15	83	83	+ 3	16
3	125	125	— 3	12	104	135	—41	13	133	146	—24	15	90	90	— 5	13
4	110	112	—12	10	140	173	—36	16	148	163	—25	12	90	90	— 7	10
5	117	125	—19	13	104	164	—51	24	100	120	—13	19	82	86	—17	20
6	95	112	—31	25	97	162	—53	25	120	140	—71	28	70	80	—28	38
7	58	70	—32	65	80	150	—58	40	82	100	—35	51	55	64	—31	72
8	44	65	—48	93	64	128	—60	92	45	60	—40	45	43	50	—33	86
9	50	52	—18	117	66	107	—51	106	54	57	—22	100	62	62	+ 6	136
10	40	42	+18	128	45	67	—48	134	21	22	—14	104	79	86	+24	156
11	63	77	+35	169	32	39	—32	145	49	65	+41	165	28	40	+45	170
Mid.	84	98	+30	193	63	64	+12	175	46	78	+53	185	28	40	+44	187

Hour.	October.				November.				December.				Annual means.			
	σ	s	α	β	σ	s	α	β	σ	s	α	β	σ	s	α	β
Mid.	33	60	+57	210	73	95	+41	197	65	83	+38	200	51	72	+43	191
1	68	92	+47	204	78	116	+48	186	39	65	+54	190	58	84	+46	200
2	60	77	+38	210	86	102	+33	212	30	60	+58	200	68	89	+41	201
3	63	75	+32	209	66	90	+43	219	58	70	+33	119	81	95	+33	205
4	106	110	+14	207	22	76	+16	190	84	86	+15	205	79	92	+20	213
5	72	74	+12	215	57	78	+48	240	32	34	+20	210	74	79	+11	219
6	51	53	—14	214	40	44	+24	282	20	20	+12	247	55	58	— 7	231
7	16	29	—58	272	60	91	—10	308	14	20	—44	240	36	46	—33	247
8	20	28	—45	316	60	60	— 1	320	17	18	—21	240	29	40	—32	268
9	32	35	—28	328	50	50	— 8	333	29	29	—10	352	24	31	—29	295
10	40	43	—23	342	65	65	— 4	333	36	36	— 4	350	27	32	—25	291
11	55	55	—12	4	47	52	—25	325	51	51	+ 2	5	35	40	— 4	0
Noon.	106	110	—13	5	42	52	—38	359	55	55	— 3	8	53	59	—14	8
1	45	50	—28	16	70	80	—29	4	61	61	— 1	8	64	68	—14	11
2	73	78	—20	14	67	96	—46	20	63	65	—14	7	80	88	—18	13
3	82	85	—15	20	68	112	—40	32	68	71	—19	6	88	98	—20	15
4	66	88	—34	20	49	80	—52	88	55	60	—25	10	85	99	—29	22
5	52	70	—40	33	64	80	—50	77	25	40	—50	20	71	90	—36	28
6	35	52	—48	76	116	124	—30	42	27	40	—44	135	67	89	—47	51
7	70	71	—10	133	44	63	—46	74	13	40	—73	100	52	74	—44	85
8	45	45	+ 3	124	72	78	+26	132	58	64	—25	155	49	64	—29	105
9	40	45	+30	130	57	57	+ 3	146	55	61	—25	147	54	59	— 8	131
10	52	70	+45	159	42	56	+41	170	32	34	—20	142	45	53	+13	145
11	31	38	+56	195	46	77	+53	180	34	46	+48	145	42	58	+38	172
Mid.	33	60	+57	210	73	95	+41	197	65	83	+38	200	51	72	+43	191

THE GLOBE MODEL CONSTRUCTED FROM THE VECTORS AT THIRTY STATIONS.

A table of the annual means derived in the same way for thirty stations was constructed, and should properly be given here, but is omitted because it differs merely by minor variations from the adjusted values used in making the 30-inch globe model, which was built up from this original data. There is some looseness in the harmony of the observations among the stations of each group, as may be expected from the many causes operating to produce local variations, and from the fact that the computations covered only one year at each station, while the

observations themselves are spread through forty years, 1841 to 1883. The fact of real agreement, however, indicates that the fundamental system is persistent, instantaneous in its development, and has no secular variation. On the large globe the wires which represent the computed vectors were inserted, twenty-four on a given parallel of magnetic latitude corresponding to a station, one for each hour. Each wire by its length and position shows the relative strength and direction of that impressed force which will change the normal terrestrial magnetic field into the one actually observed at the station at the given hour. The discussion of the observations of terrestrial magnetism has hitherto usually confined itself to the diurnal variation of each component, horizontal force, declination, and vertical force, taken separately. It is obvious that our process merely combines these variations into one resultant vector acting in space, and is not only as legitimate as the prevailing method, but very much more instructive. A detailed description of the vectors of the following system would therefore merely reproduce the facts stated at length in the several reports, of which it is an approximate combination and summary.

Since each vector wire represents the mean value of the impressed force acting on the average for a year, the system of vectors exhibits the distribution of the external field of force as deflected by the material of the earth acting as a magnet. When the individual vector wires were inserted on the globe in latitude and longitude for all the spaces available, it was easy to see in any locality the average trend of the vectors. The wires were therefore bent or adjusted a little to give a gradually varying vector system, these changes being the smoothing out of the irregularities to a legitimate extent; from the system thus constructed the vectors of the following Table 19 were measured. They form an approximate representation of the mean magnetic vector system, and this should be discussed on its merits, whatever conclusion it may lead us to adopt. The importance of the result is such as to warrant a complete computation of all available observations, in order to elucidate some minor points that still remain inadequately determined. The model represents a mean annual system of deflecting forces impressed upon the magnetic meridians of the earth, the sun being at the intersection of the equator and central noon meridian; the poles of the model are intended to represent the magnetic poles of the earth. Of course the magnetic meridians are modified into great circles on the globe.

TABLE 19.—*Deflecting vectors of the equatorial electro-magnetic field.*

[Measured on the globe model.]

[s = units fifth decimal C. G. S.; α = positive below horizon; β = in azimuth N. W. S. E.]

Station.	Mag lat.	Midnight. s	α	β	1 a. m. s	α	β	2 a. m. s	α	β	3 a. m. s	α	β	4 a. m. s	α	β	5 a. m. s	α	β
Kingua Fjord ...	+78	60	+40	140	60	+45	145	65	+50	155	73	+53	170	82	+55	180	92	+52	185
Fort Rae	76	60	+39	150	62	+46	155	70	+52	165	76	+50	180	82	+50	190	88	+50	195
Point Barrow ...	73	58	+38	155	64	+48	165	72	+50	175	80	+46	185	85	+44	195	92	+45	205
Cap Thordsen ..	71	56	+37	160	68	+48	175	76	+45	185	82	+43	195	87	+42	205	91	+40	210
Jan Mayen	69	58	+35	170	66	+45	185	74	+38	195	85	+40	205	89	+40	210	89	+40	215
Bossekop	65	60	+32	185	64	+40	195	70	+34	205	75	+46	215	60	+35	220	50	+35	225
Sodankyla	62	65	+31	195	58	+35	205	53	+30	215	48	+32	225	40	+30	235	35	+30	235
Toronto	61	10	+30	255	10	+30	230	10	+25	225	14	+25	235	17	+25	240	19	+25	245
Washington	56	18	—22	290	18	—30	290	18	—40	275	18	—40	275	18	—42	285	18	—43	295
Makerstown	55	18	—24	295	18	—33	295	18	—42	270	18	—40	285	18	—44	290	19	—44	295
Dublin	55	17	—27	300	18	—37	295	17	—44	265	17	—40	280	17	—46	290	19	—45	290
Pawlowsk	54	17	—30	300	17	—40	295	17	—46	260	17	—44	270	17	—48	295	19	—46	295
Wilhelmshaven .	51	16	+25	305	14	+28	300	12	+27	290	13	+27	305	15	+26	305	16	+25	300
Greenwich	50	16	+24	310	14	+29	300	12	+22	300	12	+30	305	14	+25	305	16	+21	300
Paris	47	15	+23	310	14	+30	300	13	+21	305	12	+32	300	15	+24	305	16	+19	300
Vienna	45	15	+25	305	13	+31	300	13	+20	300	12	+32	305	15	+27	305	18	+21	305
Pola	42	13	+27	300	13	+32	305	12	+20	305	12	+32	305	12	+32	310	15	+27	305
Los Angeles	40	13	+30	300	13	+34	310	12	+23	315	12	+34	310	14	+37	315	17	+31	305
Tiflis	36	12	+35	300	13	+37	315	14	+30	320	15	+36	315	15	+38	310	17	+36	305
Zi-ka-wei	28	9	+65	210	8	+65	225	9	+50	240	10	+42	250	11	+40	240	13	+40	225
Bombay	10	23	+35	185	22	+35	190	22	+40	185	22	+46	180	21	+43	185	20	+40	185
Madras	+ 4	21	+35	185	22	+32	195	23	+37	185	21	+45	180	20	+40	185	20	+38	190
Singapore	— 6	20	+35	190	21	+33	200	22	+35	190	21	+43	185	20	+35	195	19	+37	190
St. Helena	—11	18	+32	185	16	+32	200	18	+35	190	20	+40	190	17	+33	195	16	+35	185
Batavia	—15	16	+30	180	14	+30	195	16	+35	185	18	+35	195	13	+30	190	12	+33	180
Süd Georgien ...	—30	20	—30	70	20	—30	65	18	—30	65	17	—30	60	19	—30	50	21	—30	45
Cape Horn	—33	20	—28	75	20	—30	70	18	—32	70	19	—34	65	21	—34	45	22	—32	45
Cape Good Hope	—34	20	—27	80	20	—32	70	19	—35	70	19	—36	65	20	—37	45	23	—34	45
Melbourne	—50	18	—26	85	18	—32	70	17	—37	75	19	—38	65	20	—38	45	21	—35	40
Hobarton	—55	16	—26	85	16	—33	75	15	—40	75	17	—40	60	20	—40	45	21	—36	40

Station.	Mag. lat.	6 a. m. s	α	β	7 a. m. s	α	β	8 a. m. s	α	β	9 a. m. s	α	β	10 a. m. s	α	β	11 a. m. s	α	β
Kinqua Fjord ...	+78	93	+50	190	92	+47	195	87	+47	200	82	+37	205	58	+40	210	66	—50	350
Fort Rae	76	94	+50	195	100	+46	200	90	+39	205	78	+40	210	52	43	220	64	—48	350
Point Barrow ...	73	98	+45	205	105	+42	210	88	+37	215	65	+43	220	43	—43	340	50	—46	0
Cap Thordsen ...	71	93	+40	210	88	+39	215	75	+36	225	50	+37	230	38	—50	345	43	—43	10
Jan Mayen	69	90	+35	215	75	+37	220	55	+34	235	40	+34	235	28	—50	350	40	—40	15
Bossekop	65	46	+33	230	40	+35	230	35	+33	245	33	—33	325	26	—38	330	38	—35	20
Sodankyla	62	33	+30	240	30	+33	245	27	+32	250	27	—32	310	26	—40	285	28	—45	80
Toronto	61	21	+30	280	26	+30	285	26	+30	270	26	—30	300	26	—40	250	25	—50	145
Washington	56	19	—33	290	21	—26	285	24	—20	275	27	—25	250	29	—35	230	23	—44	130
Makerstown	55	20	—34	295	22	—29	285	24	—25	275	26	—23	245	28	—32	225	23	—39	125
Dublin	55	21	—36	295	23	—31	285	25	—28	280	26	—22	245	26	—30	225	24	—37	120
Pawlowsk	54	22	—38	295	24	—33	285	26	—30	275	27	—22	240	26	—32	225	24	—39	120
Wilhelmshaven .	51	18	+23	300	23	+22	285	26	—25	270	27	—19	245	27	—35	225	26	—40	125
Greenwich	50	18	+25	300	23	+23	285	26	—23	275	27	—18	245	27	—35	225	27	—35	125
Paris	47	18	+27	305	21	+24	300	24	+20	285	26	—20	245	27	—36	225	27	—33	130
Vienna	45	25	+28	310	22	+27	305	24	+22	290	26	—21	240	27	—38	225	27	—32	135
Pola	42	19	+29	310	21	+30	305	24	+23	290	26	—22	240	27	—38	230	27	—33	135
Los Angeles	40	19	+30	305	21	+32	310	25	+25	295	27	—24	235	26	—39	235	26	—35	140
Tiflis	36	19	+32	295	21	+35	295	25	+28	285	27	—27	235	27	—41	230	27	—38	140
Zi-ka-wei	28	15	+35	210	18	+35	220	22	+30	260	23	—42	230	23	—44	225	24	—34	145
Bombay	10	22	+37	185	23	+36	165	23	+30	140	24	—28	40	34	—28	20	43	—27	10
Madras	+ 4	22	+36	185	23	+35	165	23	+29	130	24	—25	45	35	—30	25	44	—24	20
Singapore	— 6	19	+35	185	20	+37	160	24	+29	120	27	—23	50	37	—27	30	45	—22	25
St. Helena	—11	18	+35	185	20	+39	155	24	+31	105	28	—21	50	35	—22	35	45	—20	30
Batavia	—15	15	+35	180	20	+40	150	25	+33	90	28	—20	55	33	—19	40	40	—18	35
Süd Georgien ...	—30	24	—32	40	26	—28	50	27	—30	65	28	—35	75	28	+30	115	27	+35	150
Cape Horn	—33	24	—30	45	26	—26	55	28	—27	70	29	—35	75	28	+30	120	27	+37	150
Cape Good Hope.	—34	25	—30	45	27	—23	55	29	—26	70	30	—33	80	28	+25	120	26	+40	150
Melbourne	—50	23	—30	40	25	—21	55	26	—27	70	27	—32	75	26	23	115	24	+38	145
Hobarton	—55	22	—32	40	25	—20	60	28	—30	65	27	—30	75	25	+25	110	23	+35	140

TABLE 19.—*Deflecting vectors of the equatorial electro-magnetic field*—Continued.

[Measured on the globe model.]

[s = units fifth decimal C. G. S.; α = positive below horizon; β = in azimuth N. W. S. E.]

Station.	Mag. lat.	Noon.			1 p. m.			2 p. m.			3 p. m.			4 p. m.			5 p. m.		
		s	α	β	s	α	β	s	α	β	s	α	β	s	α	β	s	α	β
Kinqua Fjord	+78	74	−51	355	85	−52	0	93	−53	10	94	−50	15	93	−47	15	90	−44	20
Fort Rae	76	72	−48	0	75	−49	10	80	−50	15	89	−46	20	94	−45	20	90	−41	25
Point Barrow	73	63	−46	5	68	−45	15	76	−45	20	87	−42	25	94	−42	25	95	−38	30
Cap Thordsen	71	57	−42	15	68	−42	20	76	−40	20	90	−39	25	100	−38	25	97	−34	30
Jan Mayen	69	54	−39	20	62	−39	25	75	−37	25	90	−36	25	102	−34	25	94	−30	30
Bossekop	65	48	−36	30	55	−36	35	70	−35	35	80	−33	30	84	−33	30	83	−30	30
Sadankyla	62	27	−35	75	35	−34	60	44	−30	55	52	−30	45	58	−32	40	62	−32	35
Toronto	61	26	−35	120	27	−30	110	26	−25	70	26	−28	60	24	−30	55	18	−40	40
Washington	56	30	−35	115	31	−26	105	29	−24	90	27	+23	70	25	+40	50	23	+42	45
Makerstown	55	30	−32	115	31	−24	100	29	−21	90	27	+24	75	26	+42	60	24	+44	50
Dublin	55	32	−34	110	31	−22	100	29	−18	90	27	+24	80	26	+40	65	24	+44	55
Pawlowsk	54	32	−35	110	32	−20	100	30	−17	90	27	+22	85	25	+39	70	23	+42	65
Wilhelmshaven	51	35	−37	115	34	−20	105	30	−18	95	25	+20	95	21	+40	80	19	+42	75
Greenwich	50	37	−35	110	36	−20	100	33	−19	95	25	+19	95	21	+40	80	18	+45	85
Paris	47	38	−35	105	36	−21	100	33	−20	95	26	+18	95	22	+38	80	18	+44	90
Vienna	45	36	−33	105	35	−22	100	30	−22	95	26	+18	100	22	+37	85	18	+42	90
Pola	42	35	−34	105	33	−25	100	30	−25	95	25	+20	95	21	+37	90	17	+45	95
Los Angeles	40	35	−35	105	33	−30	100	30	−26	95	25	+22	95	21	+38	90	17	+47	100
Tiflis	36	35	−37	100	33	−36	90	30	−29	85	24	+27	90	20	+42	110	16	+50	110
Zi-ka-wei	28	27	−42	75	26	−45	45	23	−30	65	20	+45	50	13	+48	115	15	+54	140
Bombay	10	44	−27	15	40	−33	345	37	−30	340	19	−32	315	16	+30	225	15	+35	195
Madras	+ 4	44	−28	15	40	−32	345	35	−28	340	18	−30	305	17	+32	220	16	+30	195
Singapore	− 6	44	−30	15	40	−30	345	33	−26	335	17	−28	300	17	+32	220	17	+25	200
St. Helena	−11	43	−32	10	40	−30	340	32	−25	335	15	−28	295	16	+30	220	16	+20	200
Batavia	−15	41	−35	10	38	−30	340	32	−25	330	15	−28	290	16	+30	215	17	+15	200
Süd Georgien	−30	30	+45	220	31	+40	230	32	+35	240	32	+30	260	28	−30	270	24	−40	265
Cape Horn	−33	30	+43	225	32	+38	230	32	+36	245	30	+35	260	29	−30	275	25	−40	270
Cape Good Hope	−34	28	+40	230	30	+35	230	30	+37	250	30	+30	260	28	−25	275	25	−38	275
Melbourne	−50	27	+40	230	32	+33	235	30	+38	260	30	+30	265	27	−30	275	24	−37	280
Hobarton	−55	25	+35	230	33	+35	240	28	+37	265	30	+35	265	26	−35	280	21	−40	280

Station.	Mag. lat.	6 p. m.			7 p. m.			8 p. m.			9 p. m.			10 p. m.			11 p. m.		
		s	α	β	s	α	β	s	α	β	s	α	β	s	α	β	s	α	β
Kinqua Fjord	+78	80	−42	20	68	−40	25	58	−35	30	55	−32	30	52	−28	30	44	+38	135
Fort Rae	76	82	−40	25	70	−37	25	60	−34	30	56	−31	40	54	−24	40	52	+40	140
Point Barrow	73	83	−37	30	72	−36	30	62	−36	35	57	−27	50	54	−20	45	52	+42	145
Cap Thordsen	71	86	−36	30	70	−34	30	60	−38	40	55	−23	60	55	+25	130	56	+40	150
Jan Mayen	69	84	−36	30	60	−33	35	57	−33	45	53	−20	65	53	+30	140	57	+38	160
Bossekop	65	72	−35	35	50	−30	40	45	−27	45	43	+28	140	44	+30	150	50	+34	180
Sodankyla	62	60	−34	35	42	−25	40	37	−22	50	38	+28	145	40	+30	155	47	+30	185
Toronto	61	14	−43	30	10	−44	50	9	−30	45	9	+35	330	8	+28	200	7	+20	270
Washington	56	21	+58	25	20	+56	340	19	+34	310	18	+40	300	17	+24	300	17	−24	295
Makerstown	55	24	+60	20	22	+53	330	20	+37	305	18	+37	295	17	+22	295	16	−22	300
Dublin	55	24	+58	20	21	+48	325	20	+40	305	19	+38	290	18	+22	290	16	−20	300
Pawlowsk	54	22	+56	15	21	+45	320	19	+40	310	18	+38	290	17	+27	295	16	−20	300
Wilhelmshaven	51	19	+54	25	19	+40	315	19	+42	310	19	+39	300	19	+30	300	17	−32	305
Greenwich	50	18	+54	30	19	+38	320	19	+44	310	18	+37	305	19	+35	305	18	+30	305
Paris	47	17	+56	35	17	+38	325	17	+46	315	17	+35	310	17	+38	305	17	+27	305
Vienna	45	16	+55	45	16	+40	335	15	+42	310	14	+36	305	15	+39	300	15	+33	305
Pola	42	13	+56	55	11	+45	50	10	+40	295	10	+38	300	9	+41	295	8	+45	300
Los Angeles	40	12	+58	115	11	+47	105	9	+42	140	9	+40	255	9	+45	290	8	+48	295
Tiflis	36	12	+60	125	12	+44	140	10	+43	150	9	+45	220	8	+53	230	8	+50	240
Zi-ka-wei	28	16	+32	155	18	+40	160	16	+40	175	10	+50	185	10	+60	180	9	+55	180
Bombay	10	17	+27	195	19	+30	180	21	+33	180	21	+35	180	20	+33	180	20	+30	185
Madras	+ 4	18	+24	195	21	+30	180	22	+30	180	22	+33	180	23	+30	180	24	+30	185
Singapore	− 6	19	+22	190	21	+30	185	23	+28	180	24	+30	180	24	+27	185	24	+28	190
St. Helena	−11	19	+20	190	22	+30	185	24	+28	185	25	+27	175	24	+25	185	24	+25	185
Batavia	−15	20	+18	190	22	+30	185	23	+30	185	24	+25	175	24	+25	190	24	+25	185
Süd Georgien	−30	21	−40	255	18	−45	215	18	−50	185	20	−50	120	20	−45	100	20	−35	90
Cape Horn	−33	21	−40	255	18	−45	225	18	−46	185	18	−48	125	18	−40	100	18	−35	90
Cape Good Hope	−34	20	−40	260	18	−45	240	18	−45	190	17	−45	130	18	−40	100	18	−35	85
Melbourne	−50	20	−40	270	17	−45	300	16	−45	350	16	−45	55	17	−40	70	18	−35	75
Hobarton	−55	19	−40	280	16	−44	310	16	−46	350	16	−45	65	17	−40	75	17	−38	80

CHART 14.—Deflecting forces of the electro-magnetic field with sun on central meridian.

β=Azimuth counted. 0°=north, 90° west, 180° south, 270° east. α=Altitude counted, +below surface, —above surface. s=Length of the deflecting vector force at given place and time. Red lines=forces entering the earth. Blue lines=forces emerging from the earth.

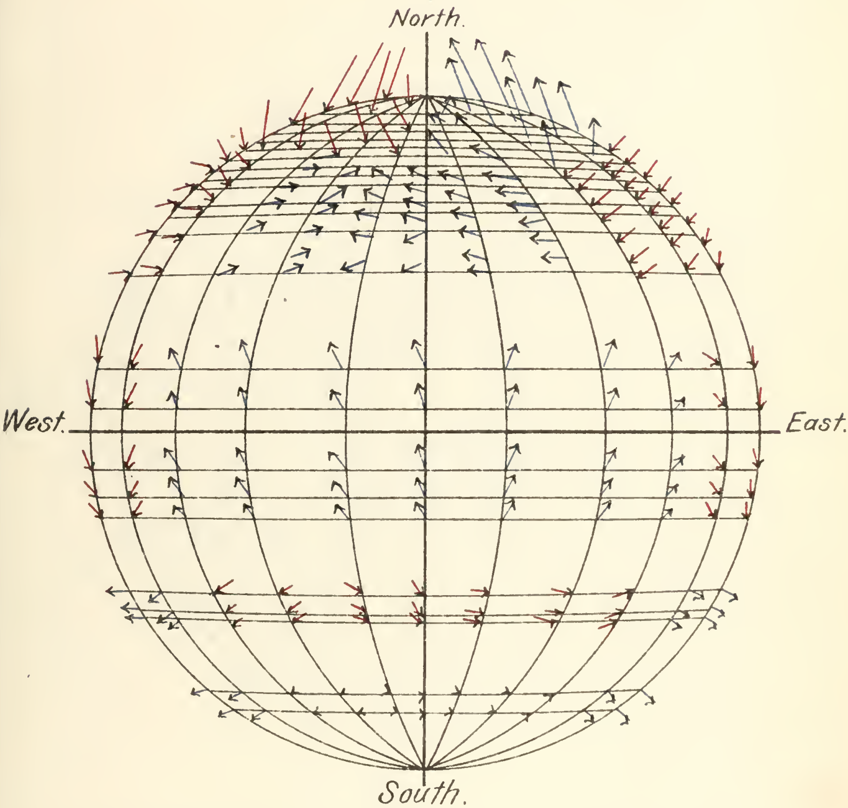


Chart 4.

Chart 14 shows the vectors of the model looked at from the sun and along its radiant lines. Chart 15 shows the same model looking down upon the north magnetic pole. The orientation and position of the stations is shown by the precepts on the diagrams. Chart 16 gives a scheme of the vectors in both hemispheres. It is once more recommended that a similar model be constructed by students who desire to have a fitting idea of this magnetic field.

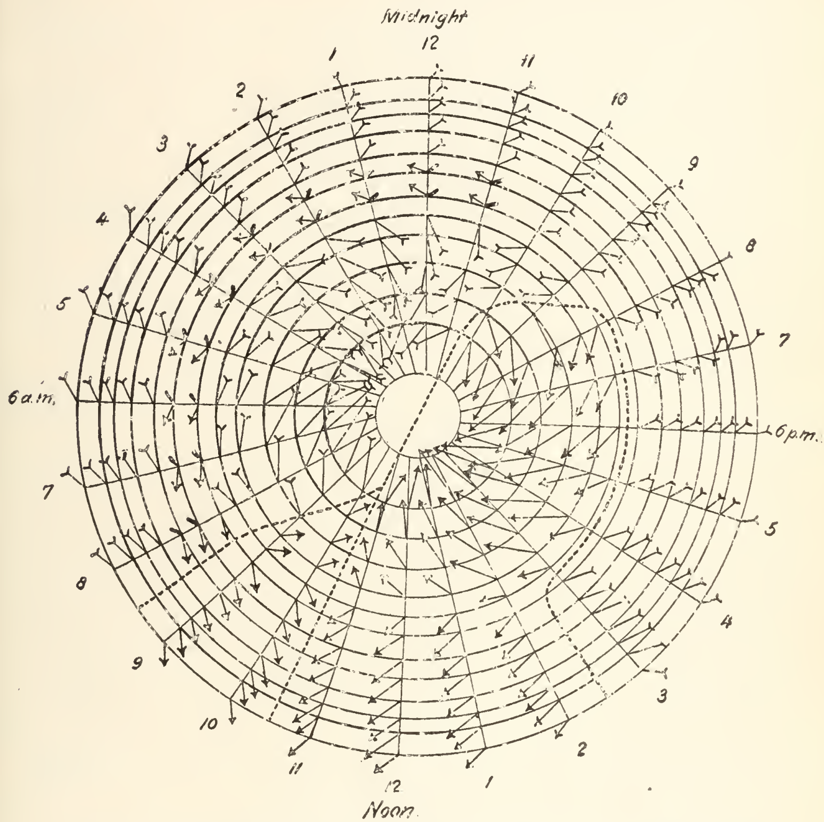


CHART 15.—Deflecting forces of the electro-magnetic field, north magnetic hemisphere.

DESCRIPTION OF THE FORCES OF THIS MAGNETIC SYSTEM.

An inspection of the model shows that it is constructed under these controlling conditions, (1) couples, (2) magnetic refraction, (3) a permeable shell. There are three distinct couples: (1) That in the polar cap, with axis in northern hemisphere on the 4 o'clock meridian. The counterpart in the southern hemisphere is not in evidence for lack of observations, but symmetry requires its existence. The vectors are strong, and vary from 0.00100 C. G. S. to .0.00040 C. G. S., the long ones spreading out and entering the cap on each side at 4 a. m., but

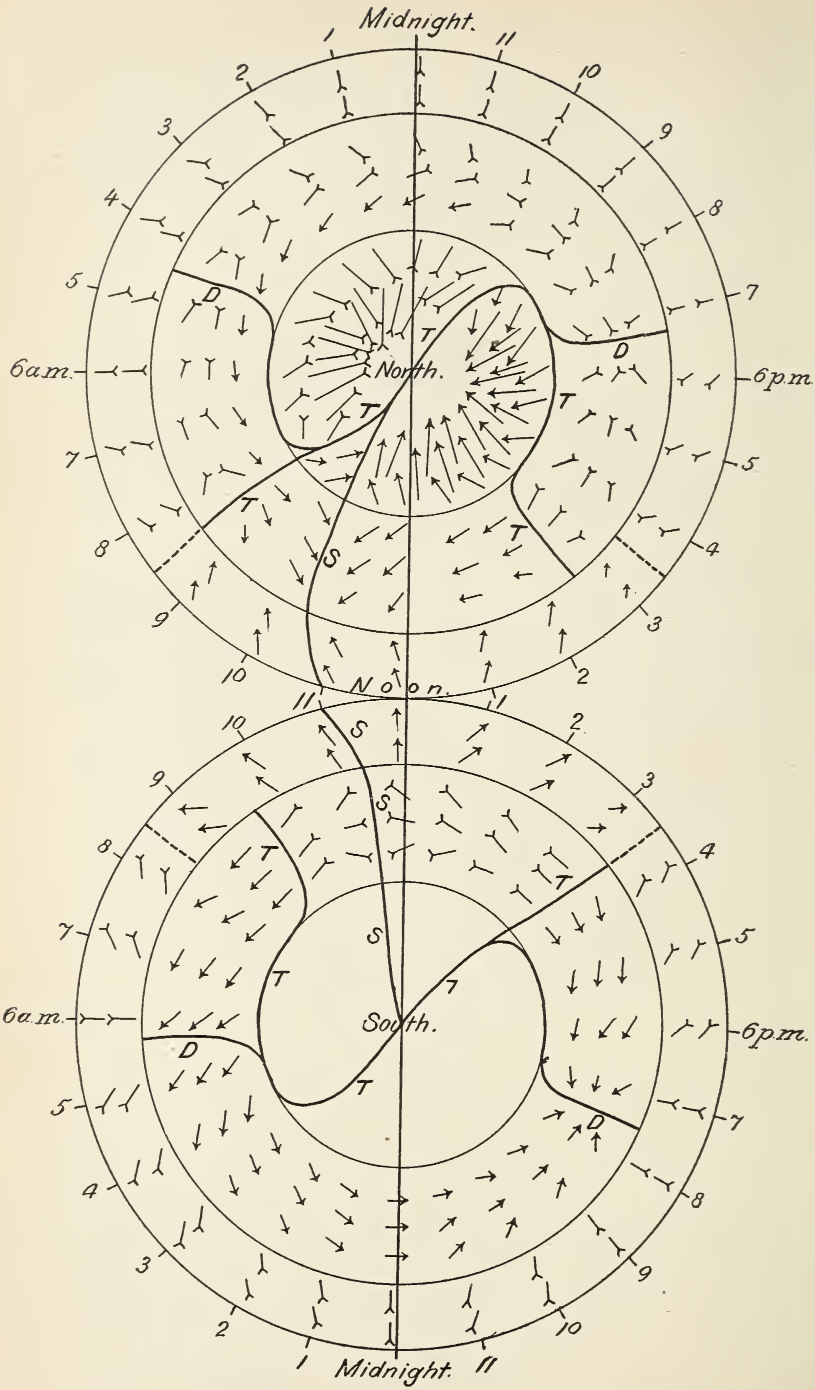


CHART 16.—Scheme of the directions of the deflecting forces causing the diurnal variations.

concentrating and emerging on the opposite side at 4 p. m. Along the 10 a. m. and 10 p. m. meridians the lines evidently pass through the cap. Probably all the entering lines are transmitted within the cap, but this is not so certain, as some lines may perhaps pass through the shell from north to south, like the lines of the polar field previously described. (2) The second couple is in the midlatitude zones, with vectors toward the sun in the northern and away from the sun in the southern hemisphere. (Chart 14.) These vectors do not converge on the noon meridian, but at 10.30 a. m., and they represent a sheet-system asymmetrically disposed to that plane on the illuminated side of the earth. Whether this is a true lag angle caused by rotation or a displacement due to the fact that the magnetic lines seek the coldest surface regions consistent with the balance of the total system, and is therefore partly a meteorological phenomenon, it is not easy to say. The corresponding plane of divergence of the sheets in the northern hemisphere is at 6.30 p. m., and in the southern hemisphere at 8 p. m. The southern hemisphere seems to be in some respects twisted about one hour in the direction of rotation relatively to the northern. (3) The third couple is in the tropical zone, with vectors emerging northward on the sun side and entering southward on the dark side of the earth. All these couples are consistent with the view that the earth, having its positive magnetism south and negative north, is placed in a field of force diminishing in strength from the sun outward, because the southern geographical hemisphere is repelled and the northern attracted. This would seem to be proof positive that the electro-magnetic field of solar radiation is capable of acting like a static field, and is one more instance of the breaking down of the distinction usually maintained, that the nature of the static and dynamic lines of magnetic force is essentially different. So-called statical lines are probably rotating vortices, the angular velocity being unknown, but great. Dynamic radiant lines are quite certainly transverse vibrations of enormous frequency, but both are essentially dynamic conditions of ether motion and should be treated from this point of view.

The phenomena of refraction is clearly seen to be a characteristic of this field of force. Thus across the north polar region there is a line of tangency where the vertical component disappears, on the west side of which the forces enter and on the east side emerge. This line extends southward between 8 a. m. and 9 a. m. to the southern hemisphere, but reverses the relative entry and emergence of the vectors. It returns between the 2 p. m. and 3 p. m. meridians, having, no doubt, crossed the south pole with its counterpart vectors. It makes a turn along the sixtieth north parallel just under the aurora belt till it joins its lines over the polar regions (Chart 15, dotted lines). Between 10 a. m. and 11 a. m. the declination component vanishes, when H and V are at a maximum. This line also passes from the north pole to the south pole, but has a tendency to become 11 a. m. or 11.30 a. m. in the southern hemisphere. It does not appear on the dark side of the earth.

There is a belt including the stations Washington, Makerstown, Dublin, Pawlowsk, near magnetic north latitude 50° extending from midnight to 6 a. m., where the sign of the vertical angle is not decisively determined. The impression from the neighboring stations on the model is that it should be +, that is entering the surface; but from the computations it is probably —, as given. There is a transition from one sheet to the other at this latitude, and its effect may, in fact, be to make the angle α negative along a narrow zone. Further attention should be paid to this region. It may be remarked that usually the passage from one system of couples to another is accompanied by small values of s, large values of α, and rapidly changing values of β.

The distribution of any system of outside forces is determined not only by the permeability of the material but by its shape as well, because a path that is limited to a narrow region inside necessarily constrains the outside force to take up such curves in the ether as will carry them to the surface at angles consistent with the index of magnetic refraction and the interior path. Hence we have in the case of a shell a system of forces (1) compelled to go through a thin cap at the poles, (2) around thin zones in middle latitudes, and (3) up and down through a thin zone in the equatorial regions. This explanation is entirely consistent with the results of the discussion of the polar magnetic field, on the view that the sunlight field has the power to act like an ordinary magnetic field as usually understood. Recalling now the conclusions of the preceding chapter, where it was indicated that we have three component fields of magnetic force to consider, namely, (1) the field from the earth's magnetization, (2) the impressed field from the normal polar magnetism of the sun, (3) the variations of these fields, the former in secular and the latter in short periods, we have yet to add the field (4) just now derived from the equatorial solar radiation. We thus advance to another degree of complication, when discussing the action of induction from vibrations of great frequency, from the motion of the mass of the earth within two outside fields, from convection currents of the atmosphere, from degeneration of all waves into Joule's heat, from atmospheric electricity, and even other types of energy.

At this place many academic questions can be raised, resulting from old theories, or from lack of understanding of the full consequences of the evidence here brought forward, but it must be remembered that discussions involving the conflict of old and new views only serve to obscure the question, unless it can be shown by fair criticism that the treatment of the observations is in some way incorrect. If the evidence is accepted as sound, then portions of the theories regarding the origin of terrestrial magnetic forces which are now held must be abandoned or else modified to meet the facts brought forward. For my part, after patient consideration of all the data, I see no reason for not accepting the views substantially as explained in my papers pertaining to these subjects.

CHANGE OF THE ENTIRE VECTOR SYSTEM IN LATITUDE WITH THE SUN'S DECLINATION.

As a proof that the vector system here attributed to the electro-magnetic field has in reality that origin, there is one fact which can not be reproduced in full in this abstract. In studying the vectors from month to month (see Jan Mayen) it is found that as the sun changes its declination the entire magnetic system follows it in both hemispheres. At each station there occurs a variation in the components, such as has been studied in the annual variations, which yet constantly refers the couples to an axis always pointing to the sun. In no other way could this occur than as a consequence of the changing aspect of the earth's field in the external field, brought about by the orbital motion of the earth around the sun. Those who seek, therefore, to account for the earth's magnetic field by atmospheric currents of convection alone, omitting impressed external fields, must show that such meteorological air currents exist as would produce not only the distribution described in the preceding but also in the present chapters. It is much more probable that certain meteorological effects must be ascribed to the action of the external fields, than that the fields themselves should be the effects of the movements of the atmosphere in convection currents.

CHAPTER 5.

SOME RELATIONS BETWEEN THE VARIATIONS OF THE TERRESTRIAL MAGNETIC FIELD AND THE METEOROLOGICAL ELEMENTS.

METHOD FOLLOWED IN COMPARING MAGNETIC AND METEOROLOGICAL DATA.

We will now briefly sketch the process employed in our own investigations, in an attempt to bring this entire subject to a more definite conclusion than has heretofore been secured. The data accessible in the publications of previous papers, such as van Bebber's, will not be referred to any further, since our effort has been to secure new evidence, especially pertaining to the United States. The conclusions reached have been based upon the careful discussion of a large mass of material, involving slow approximations and the repeated traversing the same data several times, as one difficulty after the other was cleared away. Even as matters now stand, it will require further consideration of the data in order to reach a perfect exposition of the several parts of this complex problem. Having developed an ephemeris depending upon the periodic variation of the earth's magnetic field, this was laid at the basis of further progress in the analysis, the object being simply to discover the fundamental normal curve representing the impressed solar magnetic field, and to detect the occurrence of the same periodicity in the meteorological changes of the atmosphere, if such actually exists. The process of computing the horizontal component σ, described above in Chapter 2, was extended to five European stations, for the years 1878 to 1889 inclusive. Since the ratio of the component σ to the total force s is for these stations nearly constant on the average, and since the variations of H and D are more accurately measured than those of V, the compilation of magnetic data was limited to the component σ. In Table 20 is exhibited as specimens for two years, 1878 and 1882, the observed mean values of σ. Each entry is the mean of the computed σ at Greenwich, Vienna, Prague, Pawlowsk, Tiflis, when these stations were available. Thus + 46 means that + 0.000046 is the mean σ for January 8, 1878, in C. G. S. units for five stations. In order that no bias might attach itself to the first derived form of the normal curve, it was assumed that, if certain days of the period possess an excess of force over others, this would be declared by an increase of the absolute numerical values on such days. The

mean of these tabular quantities was therefore taken without regard to sign; and it is shown on the line marked "mean," for each year. Afterwards these numbers were added algebraically, using all the signs. Then the series of annual means, 1878–1889, was collected into one table, and the final mean taken for the entire interval. These numbers were plotted into a curve of relative values, and it gave substantially the form presented in chapter 1, chart 9, which is the normal type finally settled upon, except that the minor crest at day 8 was lacking, and the double crest from days 17 to 19 was merged into one sweep.

TABLE 20.—*Variations of the horizontal force σ, for 1878 and 1882.*

[Units sixth decimal, C. G. S.]

	1	2	3	4	5	6	7	8	9	10	11	12	13
1878.													
Jan. 8.50	+ 46	+ 36	+ 46	− 73	− 59	− 64	− 45	− 33	+ 65	+ 55	+ 52	+ 39	+ 67
Feb. 4.18	+ 51	+ 42	− 61	− 74	− 50	− 27	− 26	− 45	− 37	+ 54	+ 85	+ 47	+ 59
Mar. 2.86	+ 39	+ 64	+ 59	+ 55	+ 71	+ 70	+ 45	+ 41	+ 26	− 50	+ 76	+ 68	+ 67
Mar. 29.54	+ 32	+ 36	− 25	+ 45	+ 88	− 90	− 26	+ 38	+ 25	+ 52	+ 69	+ 71	+ 54
Apr. 25.22	+ 71	+ 56	+ 73	− 74	− 36	− 61	+ 55	− 60	− 64	+ 43	− 77	+ 66	+ 90
May 21.90	− 45	+ 29	+ 51	− 50	− 56	− 49	+ 39	+ 37	+ 53	+ 42	+ 39	+ 48	+ 66
June 17.58	+ 96	+ 90	+ 59	+ 77	+ 84	− 68	− 79	− 78	− 98	− 71	+ 83	+120	+ 72
July 14.26	− 74	− 21	+ 36	− 93	− 82	−106	− 76	+ 83	+ 53	+ 51	− 42	− 50	+ 74
Aug. 9.94	−116	− 52	− 48	− 35	− 47	+ 33	− 37	+ 37	+ 49	+ 29	+ 77	+ 60	+ 45
Sept. 5.62	− 63	− 54	− 59	− 60	− 72	− 78	+ 61	+ 48	+ 37	− 39	+ 40	+ 84	+ 83
Oct. 2.30	− 71	− 55	− 75	− 67	+ 82	− 86	+ 62	− 53	+ 44	+ 38	+ 27	+ 57	− 31
Oct. 28.98	− 61	+ 45	+ 83	+ 33	−106	−109	+ 90	−172	−156	−105	− 97	−121	− 99
Nov. 24.66	+120	+ 86	+150	+169	+146	+111	+115	−119	−102	+ 49	+ 67	− 41	− 69
Dec. 21.32	− 29	+ 41	+ 49	+ 52	− 42	+ 55	+ 50	+ 42	+ 58	+ 50	− 96	− 77	+ 84
Mean	65	50	63	68	73	72	58	63	62	52	96	67	69
D	−218	−125	−207	−117	+ 51	−221	+ 60	+ 70	+155	+ 80	+213	+272	+151
I	+214	+468	+545	+ 22	−131	−248	+168	−304	−202	+118	+ 90	+ 99	+411
1882.													
Jan. 14.90	− 51	− 44	− 71	+ 31	+ 56	−158	−195	− 82	− 59	+ 41	− 78	+ 61	+ 85
Feb. 10.58	− 85	−134	+ 67	+ 59	− 59	+ 45	− 61	+ 99	− 64	+ 81	−213	−178	−125
Mar. 9.26	−188	−166	−104	+ 55	+ 77	− 74	+ 57	− 89	+ 58	+102	+ 85	−139	−108
Apr. 4.94	+ 48	+ 82	+ 46	+ 81	+ 92	+ 76	+146	+184	+196	+279	+120	+ 89	+155
May. 1.62	− 52	−121	+124	+ 76	+ 58	+ 60	+ 80	+ 66	+155	+178	+125	+ 71	+ 62
May. 28.30	− 92	− 80	+ 69	+ 80	+ 79	− 73	+ 87	+105	+155	+150	+118	+141	+140
June 23.98	− 79	−165	−314	−160	−182	−124	−124	− 90	− 51	+ 86	+ 72	+141	+ 42
July 20.66	+ 71	+181	+115	+120	+144	+116	−130	− 85	+ 86	+160	+119	−217	−233
Aug. 16.34	+ 74	− 47	+ 59	+ 81	+ 76	+ 87	− 71	− 56	+121	+108	+ 63	+ 78	− 82
Sept. 12.02	+ 73	+ 82	+ 71	+ 82	+ 72	+ 84	+ 81	+102	+ 70	+ 54	+ 67	+ 83	+201
Oct. 8.70	−100	− 66	− 34	+ 56	+ 54	+ 95	+ 80	− 67	+103	+112	+108	+130	+169
Nov. 4.38	+186	+234	+195	+163	+147	+105	+204	+265	− 86	−356	−135	+147	+151
Dec. 1.06	+ 98	+ 96	+151	+114	+ 77	+118	+124	+141	+106	+116	+120	+ 55	+ 80
Dec. 27.74	+ 64	+ 59	+ 82	+ 81	+ 82	+ 47	+ 41	+ 56	+100	+ 96	− 84	− 66	− 64
Mean	90	107	103	89	90	90	106	105	101	127	108	114	121
D	−213	−316	+ 70	+445	+358	+130	− 68	− 37	+329	+594	− 51	− 31	+ 76
I	+180	+164	+450	+474	+415	+274	+387	+571	+561	+690	+539	+427	+397

TABLE 20.—*Variations of the horizontal force б, for 1878 and 1882.*

[Units sixth decimal, C. G. S.]

14	15	16	17	18	19	20	21	22	23	24	25	26	27	M.P.T.
+139	+140	+51	—197	—95	—60	—41	—30	—51	—37	—32	—64	—51	+48	I
+51	+49	+54	+69	+28	+43	—97	—94	—76	—118	—48	—29	+83	......	I
—79	—77	—103	—92	+80	+57	+47	+63	+53	+40	—41	—35	+88	+60	I
+66	+54	+74	+85	+104	+56	—71	—86	—71	—29	—47	—42	—24	—43	D
+55	+83	+71	+56	+93	+67	—133	—112	—99	—66	—78	—69	—49	......	I
—162	—198	—98	—91	+47	+81	+87	+58	+46	+57	+83	+100	+84	+111	I
+44	+52	+39	+43	+49	+53	+116	+72	+50	—26	—52	—44	—31	—56	I
+17	+28	—58	—41	—49	+37	+75	+73	+46	—32	—47	—79	—113	......	I
+43	+23	+48	+73	+50	+36	—44	—44	+57	—37	—58	—58	+51	+50	D
+67	+40	+58	+60	+83	—99	+58	+39	—68	+22	+27	—73	—57	—39	D
—31	—11	+45	—92	—87	—91	—74	+88	+81	+47	+24	+55	+53	......	D
—95	—102	—100	+89	+56	+85	—63	—69	+63	+40	—58	+60	—42	+49	I
—58	+29	+41	+32	+45	+86	—82	—42	—35	+40	+61	—45	—34	—58	I
+68	+79	+96	+101	+87	+97	+90	+43	+55	+115	+132	+103	+124	+55	I
70	69	67	80	68	68	77	65	61	50	56	61	63	57	64
+145	+106	+225	+126	+150	—98	—131	—3	—1	+3	—54	—118	+23	—32	....
—20	+83	—7	—31	+341	+546	—1	—38	—74	+19	—80	—102	+59	+209	....
+77	+99	+117	+81	+113	+122	—163	+98	+103	+83	+88	—143	—173	—92	D
+71	+61	+58	+93	+76	+39	+59	+106	+51	+47	—25	—32	+51	+25	D
+120	+90	+86	+124	+175	+87	+93	+158	+125	+160	+164	+146	+172	......	D
—1044	—566	—209	—378	—349	—236	—131	—138	+64	+62	+82	+97	+104	+61	I
—172	—157	—110	+71	—89	—53	+92	+61	—89	—63	+52	+69	+78	+78	I
+144	+173	+103	+63	+143	—172	—145	—154	—53	—80	+125	—148	—101	......	I
+86	+74	+63	—137	—48	—43	+67	—62	—58	+101	+139	—109	+92	+76	I
—118	—56	—92	—255	—153	—148	—95	—80	—121	—50	+112	+106	+73	+99	I
+78	+74	+113	+160	+126	+85	+64	—180	+49	+27	+24	+56	+56	+54	D
—211	—56	—72	—65	—84	+78	+258	+235	—400	—258	—132	—375	—180	......	D
+180	+144	+47	+87	—98	—61	+69	—97	—85	+60	+130	+170	+244	+214	D
—248	—1135	—274	—964	—650	—282	—141	—75	—164	—142	—101	—90	+104	+134	I
+94	+144	—177	—76	—66	—126	—267	—345	—259	—101	—107	—50	+66	......	I
—42	+49	+47	+68	+58	+49	+52	+45	—62	+45	+55	—82	—61	+89	D
126	120	105	127	124	111	119	124	109	91	95	111	111	92	108
+273	+461	+396	+548	+366	+399	+424	+365	—69	+172	+304	—135	+106	+290	....
—464	—322	—672	—829	—713	—1028	—603	—698	—671	—273	+302	—125	+419	+448	....

Next it was sought to find out whether there is a similar curve in the several meteorological elements, and the data derived from the pressure and temperature was compiled on precisely the same plan for a series of years; certain rough curves, bearing a striking resemblance to the type curve, emerged as the result of almost every application of the ephemeris to the data of meteorological observations. This crude result was presented in a paper read before the International Meteorological Congress, Chicago, August, 1893. Experience with this curve in its application to individual periods of the ephemeris, gradually strengthened the conviction that the tendency to recur was continuous, and not confined merely to the mean value of a long tabulation, as might perhaps have been objected was the case. The pursuit of these individual repetitions of the type curve, amid all the loosely constructed irregularities constituting the recorded meteorological changes, has been a most laborious and tantalizing task, and yet one absolutely necessary to perform, if a definite result is demanded. It is necessary here to omit a large block of material in the form of curves which represent the observations.

One fact greatly tends to obstruct the detection of the normal curve in the meteorological field of middle latitudes, namely, the rapid eastward drift of the atmosphere, and the confused circulation attending the passage of the anticyclones and the cyclones over the United States. In order to study the eastward movement carefully, and to discover the regions responding most sensitively to this impressed magnetic impulse, the territory of the United States east of the Rocky Mountain crest was divided into groups, as described in the paper, "Inversion of temperatures" (Amer. Journ. Sci., Dec., 1894). The mean temperature of the reporting Weather Bureau stations, at the 8 a. m. and the 8 p. m. observations, for each group, was plotted on a scale of 1 cm. per day, the broken line joining the ordinates representing the actual variation of the mean temperature recorded in that region. Similarly the pressures were reduced to a representative line. The diurnal variations, the rapid changes attending the passage of "highs" and "lows," also the slower changes pertaining to seasonal conditions, are thus graphically displayed in a form suitable for critical examination. Beginning with the extreme northwest—that is, the western Canadian stations north of Montana—the dates of the magnetic ephemeris were superposed upon the common calendar dates and a line was drawn through the successive groups, sloped forward just enough to display the average advance of weather conditions to the east and south in that district, so that the individual crest of temperature or pressure continues at the same distance from this initial line. Thus the periods of the ephemeris may be applied to any district of the United States, and they will be correct to the degree in which the conditions propagated eastward represent the original form of the curve in the northwest. It was found by matching the normal curve with these graphic

lines that there is a definite recurrence in the meteorological changes. The long sweep of the curve, as well as the minor crests, greatly assisted the matching of the curves. It was perceived that the succession of changes on the eastern slope of the mountains, to the north of Montana, lying under the auroral belt, was approximately of the same type as the normal curve, in spite of many irregularities. This is also true of the Dakotas, allowing one day to elapse on the ephemeris. Such comparison of the conditions of the weather maps with the type curve has been practised with persistency from day to day for several years, and the agreement seems to continue as regularly now as when this work began. We have five or six complete rolls of these temperature and pressure changes, each roll covering one year.

THE PHENOMENON OF INVERSION OF THE NORMAL CURVE.

Unfortunately for the rapid progress of the investigation, the conclusion gradually shaped itself that the normal curve had a tendency to invert on its long axis during certain periods. An intercomparison of the periods presented such evidence that it was not possible to put this idea aside. The sequence of the inversion was at first apparently lawless, so that no cause or reason for it could be readily assigned. The detection of the law of inversion has, however, served to place the entire subject of direct solar magnetic action in a new aspect, and greatly adds to the probability of the truth of that theory. The looseness of the individual curves relatively to the normal form is evidently due to the feeble impressed magnetic force operating on the atmosphere; to the fact that the convectional circulation overpowers the magnetic impulse at times; and to the wide and unsteady deviation of the solar output itself from its mean normal type. If a perfect match between the normal and the observed curves is demanded, it can be procured only by the existence of perfect conformity on the part of the sun to the normal type in each period, and also on the *condition that the magnetic force is alone responsible for the observed meteorological impulses*, which of course is not the case, because this would be equivalent to annihilating the effect of the temperature gradient between the equator and the poles. All that we claim exists is, an impulse derived from the magnetic field, which tends to make the convectional system of atmospheric currents culminate in "highs" and "lows," respectively, on the dates of the excess or defect of the solar magnetic force by means of the well-known law of physics, that cooling the medium containing magnetic force increases its strength, and its converse, that an increase of magnetic force cools the medium. The cooling of the air in a stronger magnetic field tends to precipitate "highs" on the northwest of the American continent, in conjunction with the mean trend of the seasonal isobars. The relaxing of this tendency in a weaker magnetic field allows the "lows" from the North Pacific to work in upon the continent or else to form along the eastern edge of the mountain divide, as has

been shown to be the case in the local origination of two-thirds of the United States storms. (Bulletin No. 21, Storms and Storm Tracks.) This view calls for no unusual physical conditions, and it is believed to represent simply the facts observed in connection with the formation of the current American weather.

DISCOVERY OF THE LAW. OF INVERSION.

A process will now be briefly summarized that has cost much time and labor in the effort to discover the law of the inversion of the normal-type curve, leaving the explanation of the reason of the same for the following chapter. In the Table 21 of direct and inverse types appear four systems, marked T, M T, M P T, and M, respectively. M stands for European magnetic horizontal component σ, P for barometric pressure in the northwest of the United States, T for temperature in the same districts. M is the mean value of 5 stations, P of 10 stations, and T of 10 stations usually, the latter being generally the Dakota or Upper Missouri Valley stations. In the case of the magnetic system, preceding 1878 the horizontal force alone was employed—that is, without composition with the declination. Several stations, when available, were taken simultaneously and in widely separated latitudes, as Toronto, Greenwich, St. Helena, Singapore, Cape of Good Hope, and Hobarton. The values, derived directly from the published reports of magnetic observations in mean groups, or singly for the earlier years, were transferred to form graphic traces, distributed in the periods of the 26.68-day ephemeris. For an example, the periods beginning August 3.58, 1845, and November 18.30, 1845, are shown on charts 17, 18. The curves are made by extracting the values from the volumes whose pages are indicated just beneath the names of the stations, and are plotted on such a scale as will reduce them to the same amplitude, the scale being placed at the beginning of each curve. Underneath the group is found the type curve from chart 9. Now, two facts are readily seen—that all these curves rise and fall together, and that therefore the horizontal force increases and diminishes simultaneously over the entire earth, which really proves the existence of an external magnetic field in composition with the normal terrestrial field. The other fact is that the first period apparently agrees with the direct type and the second with the inverse type of the normal periodic curve.

CHART 17.—Variation of the horizontal force. Period beginning August 3.58, 1845. Illustrates a direct type period.

CHART 18.—Variation of the horizontal force. Period beginning November 18.30, 1845. Illustrates an inverse type period.

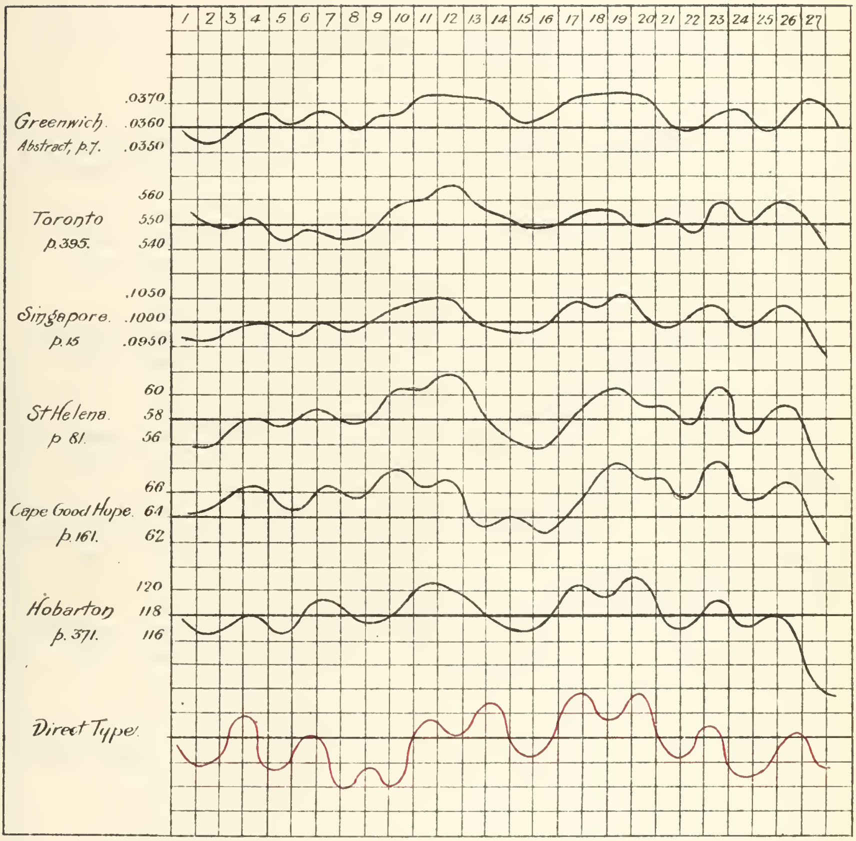

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
Greenwich. Abstract, p.7.
.0370
.0360
.0350
Toronto p.395.
560
550
540
Singapore. p.15
.1050
.1000
.0950
St Helena. p 81.
60
58
56
Cape Good Hope. p.161.
66
64
62
Hobarton p.371.
120
118
116
Direct Type.

Chart XVII.

TABLE 21.—*Direct and inverse types, found by trials.*

T. SYSTEM.

Periods.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1878......	D	I	I	I	I	D	D	I	D	D	D	I	D	D
1879......	I	I	D	I	I	I	D	D	D	D	D	D	D	D
1880......	D	D	D	I	I	I	I	I	I	D	D	D	I	
1881......	D	D	I	I	I	I	D	D	D	I	I	I	D	I
1882......	D	D	D	D	D	I	I	I	I	I	I	I	I	D
1883......	D	D	D	D	D	I	I	I	I	D	I	I	I	
1884......	D	D	D	D	D	I	I	I	I	D	D	D	D	I
1885......	D	D	D	D	D	I	I	I	I	I	I	D	D	I
1886......	I	D	I	D	D	I	D	D	D	D	D	I	I	
1887......	I	I	D	I	I	I	D	I	I	D	D	D	D	I
1888......	I	I	I	I	I	I	I	D	D	D	D	D	D	I
1889......	I	D	I	I	D	D	D	D	D	D	I	I	I	
1890......	I	I	D	D	I	I	I	I	D	D	D	I	D	I
D......	7	8	8	6	6	2	6	5	7	10	8	6	8	4

M. T. SYSTEM.

1878......	I	I	I	D	D	I	D	I	D	I	I	D	D	D
1879......	D	I	D	D	I	I	I	D	D	D	D	D	D	D
1880......	D	D	I	I	D	I	I	I	I	D	I	D	I	
1881......	I	I	I	D	D	D	D	I	D	I	I	I	I	I
1882......	I	D	I	I	I	I	D	I	D	D	D	I	D	D
1883......	I	I	I	D	I	I	I	I	I	D	I	I	I	
1884......	D	D	D	D	D	I	I	I	I	I	I	I	D	I
1885......	D	D	D	D	I	I	D	D	I	D	D	I	I	I
1886......	I	D	I	D	I	I	I	I	D	D	D	D	I	
1887......	D	I	D	I	I	D	D	I	D	I	D	D	I	D
1888......	D	D	I	I	I	I	D	I	I	D	D	D	I	I
1889......	I	D	I	I	I	I	D	D	D	D	D	I	I	
1890......	I	I	I	I	I	D	I	I	D	D	I	D	I	I
D......	6	7	4	7	4	3	7	3	8	9	7	7	4	6

M. P. T. SYSTEM.

1878......	I	I	I	D	I	I	I	I	D	D	D	I	I	I
1879......	I	I	D	D	I	I	D	D	D	D	D	I	I	D
1880......	D	D	I	I	D	I	I	I	I	D	I	D	I	
1881......	I	D	D	D	D	D	D	I	D	I	I	I	I	I
1882......	D	D	D	I	I	I	I	I	D	D	D	I	I	D
1883......	D	D	D	I	I	I	D	D	D	D	I	I	I	
1884......	D	D	D	D	D	I	I	I	I	I	I	I	D	I
1885......	D	D	D	D	I	I	I	I	I	D	D	D	I	I
1886......	D	D	I	D	I	I	I	D	D	D	D	D	I	
1887......	I	I	I	I	I	D	D	I	I	I	D	D	D	I
1888......	D	D	I	I	I	I	D	D	I	D	D	D	D	I
1889......	I	D	D	D	I	D	D	D	D	D	I	I	I	
1890......	I	D	I	I	I	I	I	I	D	D	D	I	D	I
1891......	I	I	D	I	D	I	I	D	I	I	I	I	I	D
1892......	I	D	D	D	I	I	I	D	D	I	I	I	I	I
1893......	D	D	D	I	I	D	D	D	I	I	I	D	D	
D......	8	12	10	8	4	4	7	8	9	10	8	6	5	4

TABLE 21.—*Direct and inverse types, found by trials*—Continued.

M. SYSTEM.

Periods.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1841......	I	D	D	D	D	I	I	D	D	D	D	D	I	
1842......	I	D	D	D	I	I	I	D	D	D	I	I	I	I
1843......	I	I	D	D	I	I	I	D	D	D	D	D	I	I
1844......	I	I	I	D	D	I	I	D	I	D	D	I	I	
1845......	D	D	D	D	I	I	I	I	D	D	D	I	I	I
1846......	I	I	D	D	D	D	I	I	D	D	D	D	I	I
1847......	I	D	D	D	I	I	I	I	D	D	D	I	I	
1848......	I	I	D	I	D	I	I	D	D	D		.....	.....	.....
1849......	I	I	D		.....	.....	.....	D	D	D	I	I	I	I
1850......	I	D	D	I	I	I	I	D	D	D	D	I	I	I
1851......	I	D	D	D	D	I	I	I	D	D	D	I	I	
1852......	I	I	D	D	I	I	I	I	D	D	D	I	I	I
1853......	D	D	D	D	I	D	I	D	D	D	D	I	I	I
1854......	D	D	D	D	I	I	D	I	D	I	I	I	I	
1855......	D	D	D	D	I	I	I	D	D	D	I	I	I	I
1856......	I	I	D	D	I	I	D	D	D	D	D	I	I	D
1857......	I	I	D	D	D	I	I	I	D	D	D	D	I	
1858......	I	I	I	D	I	I	I	I	D	I	D	D	I	D
1859......	I	I	I	D	D	I	I	D	D	D	I	I	I	I
1860......	I	D	D	D	I	I	D	D	D	I	D	I	I	
1861......	D	D	D	D	D	I	I	D	D	D	I	I	D	D
1862......	I	D	D	D	I	I	I	D	D	D	D	I	I	I
1863......	I	I	I	D	D	D	I	I	D	D	I	I	D	I
1864......	I	I	D	D	I	I	I	D	D	D	D	I	I	
1865......	I	I	D	D	D	I	I	I	D	D	D	I	I	I
1866......	I	I	D	D	I	I	I	I	D	D	I	I	I	I
1867......	I	D	D	D	I	I	I	I	D	D	D	D	I	
1868......	I	I	D	D	D	I	I	I	I	D	D	D	I	I
1869......	D	D	D	D	I	I	D	D	D	D	I	I	I	D
1870......	I	I	I	D	D	I	I	D	I	D	I	D	I	
1871......	I	I	D	D	I	I	I	D	D	D	D	I	I	I
1872......	D	D	D	D	D	I	I	D	D	I	D	I	I	I
1873......	D	D	D	I	I	I	D	D	D	D	I	I	I	
1874......	I	D	D	I	I	I	D	D	D	I	I	D	I	I
1875......	D	D	I	D	I	I	I	D	I	D	D	I	I	I
1876......	I	D	D	D	I	I	I	D	D	I	I	D	D	I
1877......	I	D	D	D	I	I	I	D	D	D	I	I	D	
1878......	I	I	I	D	I	I	I	I	D	D	D	I	I	I
1879......	I	I	D	D	I	I	D	D	D	D	D	I	I	D
1880......	D	D	I	I	D	I	I	I	I	D	I	D	I	
1881......	I	D	D	D	D	D	D	I	D	I	I	I	I	I
1882......	D	D	D	I	I	I	I	I	D	D	D	I	I	D
1883......	D	D	D	I	I	I	D	D	D	D	I	I	I	
1884......	D	D	D	D	D	I	I	I	I	I	I	I	D	I
1885......	D	D	D	D	I	I	I	I	I	D	D	D	I	I
1886......	D	D	I	D	I	I	I	D	D	D	D	D	I	
1887......	I	I	I	I	I	D	D	I	I	I	D	D	D	I
1888......	D	D	I	I	I	I	D	D	I	D	D	D	D	I
1889......	I	D	D	D	I	D	D	D	D	D	I	I	I	
1890......	I	D	I	I	I	I	I	I	D	D	D	I	D	I
1891......	I	I	D	I	D	I	I	D	I	I	I	I	I	D
1892......	I	D	D	D	I	I	I	D	D	I	I	I	I	I
1893......	D	D	D	I	I	D	D	D	I	I	I	D	D	
1894......	I	I	D	D	D	I	I	D	D	I	I	I	D	D
D......	17	32	42	41	18	7	13	33	43	41	30	16	10	12
25........	−8	+7	+17	+16	−7	−18	−12	+8	+18	+16	+5	−9	−15	−13

GENERAL LAW.

	I	D	D Max.	D	I	I Min.	I	D	D	D Max.	D	I	I Min.	I

In an entirely similar manner the comparison has been made throughout this portion of the work, whose result is tabulated under the several systems now being described. Likewise, for the years 1878–1890, inclusive, the temperature curves were constructed for the Dakotas giving the T system; for 1878–1890 these same temperature curves, together with the European magnetic curve, were plotted in juxtaposition and taken as a pair in each period, producing the M T system;

for 1878–1893 the European magnetic curve, and the pressures and temperatures of the northwest, were also plotted in groups of three for each period, placed directly together so that the data of the same date fell on one vertical line, counting the Dakota data as one day elapsed, and they gave the system M. P. T.; finally, for 1841–1877, the magnetic curves from several parts of the world were collected in periods, the stations being placed to show synchronous action (Charts 17 and 18); for 1878–1894 the M. P. T. system was repeated in the M. table. It may be remarked in passing that these mean daily values of magnetic force indicate no eastward drift in longitude, such as B. Stewart supposed to exist in "magnetic weather," because these values are means for twenty-four hours. Such a superposition of material, gathered from all portions of the earth, if it should display any sympathetic and harmonious variations, indicates evidently some cosmical origin, and excludes as the primary causes any form of merely local changes. Having such general simultaneous disturbances, if any one attributes them to electrical or meteorological currents, then these must be shown to have a source capable of sustaining the observed effects. Variation of strength of an external magnetic field, in which the earth is immersed, will produce general disturbances of the entire terrestrial magnetic system, but that such states of the atmosphere as are known to meteorologists should by a counter process affect at once the entire system of atmospheric circulation in both hemispheres is not at all probable. It must be remembered that we are now dealing exclusively with mean values of twenty-four hours, and that diurnal changes are outside of our consideration. Hence if the electro-magnetic field does not change in intensity from day to day, appreciable variations in solar insolation having never been observed, or if the meteorological system taken as a whole is not self-active, that is, is not a primary source of energy, the only alternative in the argument is the variability of the polar magnetic field of the sun. We have shown that this is variable not only from meridian to meridian on the sun, but also that aperiodic impulses traverse the cosmical magnetic field in small and large disturbances, and it may be with minute wave-like pulations superposed upon the normal field of force. Ebert sums up the well-known facts derived from the terrestrial observations as follows (Mag. Kraft., p. 52):

> The movement of the lines has furthermore a yearly period, which expresses itself in this way, that the declination needle in both hemispheres points more easterly by some fractions of a minute of arc when the sun is north of the equator, that is, in our summer, and again more westerly when the sun is in the southern hemisphere during our winter. Likewise the inclination needle in both hemispheres shows an increase in the inclination in the season December, January, and a decrease of the same during July, August. In our winter, October to March, the intensity is greater in all parts of the earth than in the remainder of the year.

These changes are easily explained by the fact that in the approach of the earth to the sun in our winter it must pass into stronger parts of the magnetic field of the sun, and thus cause an increase of intensity of the

earth's force and an increase of inclination simultaneously all over the earth, on the principles already described.

There is one important argument to guard against. It may be said that the meteorological temperature changes precede and affect proportionally the observed strength of the magnetic field; but it will be conceded that the direct comparison of European magnetic data with the American meteorological system excludes this supposition, especially in view of the fact that no series of magnetic observations has ever been made in the northwest of the United States. Furthermore, magnetic observations are always conducted in rooms from which even the local temperature variations are practically excluded. On the other hand, this research has been greatly impeded by the total lack of a suitable series of magnetic observations in the Rocky Mountain districts; that is, one comprising several stations maintained continuously for a number of years. Toronto has a splendid series of observations, covering many years, which ought to be published; Washington has published a short series of three years; Los Angeles a ten-year series, but not for the same interval as Washington; San Antonio is not yet published. The Weather Bureau has enjoyed complete access to all these records, but they are not sufficient for the proper study of the problem now before us, chiefly because the observations are not simultaneous. An earnest hope is expressed that the United States may soon begin to make systematic observations, of equal value with those now going on under the European Governments. The available ground of comparison between the European magnetic and the American meteorological systems lies in the fact that the magnetic variations in Europe are proportional to the external field just outside the earth, which is impressed at the same time upon both hemispheres. The local peculiarities of any region, as the extreme northwest of the United States, can not, however, be carefully studied. This has constituted a barrier against the prosecution of this work to its completion, especially in its application to the problem of forecasting.

There are other remarks required concerning the comparison of the type curve with the individual periods to determine whether a given period is direct, D, or inverted, I. These two differ only in turning the same curve over on the long axis, the types being those given in Chapter I, Chart 9. (1) The distortions of successive periods are very great as compared with one another, arising from several interacting systems of forces. We are attempting to detect a delicate action, well-nigh buried among the other operations within the atmosphere. The work has been unusually difficult in many ways, especially in consequence of the fact that the periods can not always decisively be assigned to either type. (2) It was soon perceived that these irregularities are so great as to render it necessary to employ a large mass of material in order to extract a general law, and for this purpose fifty years of magnetic data are included. (3) It might be supposed that the grand sweep of the curve could be best depended upon to detect

the type, but on the whole it has been found that the sequence of the minor crests is more reliable, though both features are always considered together in an assignment of type. (4) This comparison of curves should always be done so as not to carry any preconceived impression of the probable type along from period to period, and therefore skipping about at random among the periods was the usual course followed. (5) An intercomparison of the four derived systems of types shows that about 70 per cent of the periods had a similar assignment, indicating that there is a decided probability in favor of a real inversion of the type curve. The systems herewith presented are merely the scaffolding of our investigation, and will be finally replaced by the general law of reversal which has emerged into view. It may be stated that I did not suspect what the law of the direct and inverse types was till I had finished the trial systems, and then discerned that the same law was to be found in each of them.

Referring to the D I Table 21, it is pointed out that each year was divided into the thirteen or fourteen periods given by the ephemeris; that a D or an I is inserted to indicate the probable conformity of the type curve to the curve derived from the observations in the direct or the inverse position during each period. Of course a transition may have occurred from one type to the other during a period, but the type covering the majority of days is entered. By using the four different systems of curves, extending over many years, an opportunity was presented for deriving contradictory results if the apparent conformity was really accidental; but the four results obtained having the same general conclusion, must be accepted as evidence that the observations lead to a single simple fundamental law. By carrying the work back over fifty years the ephemeris is sharply checked, because a small error in the period would throw the crests athwart the hollows of such a rapidly fluctuating curve within a few years; yet no sliding, even to the amount of one-tenth of a day, is believed to exist as far back as 1841. Every ten years of the system will give substantially the same law of relative frequency, which is a maximum of the D type during the 2, 3, 4 and the 8, 9, 10, 11 periods, and a maximum of the I type in the 5, 6, 7 and the 12, 13, 14, 1 periods. Near the middle of these groups the prevailing type is more firmly brought out than at the transition periods, where the neutral positions are occupied and a general uncertainty in the type to be assigned is likely to occur.

In Chart 19, with heading "Semiannual period of the direct type," the relations of the planes of the ecliptic, the sun's equator, the earth's equator, as projected in June on a plane perpendicular to the radius from the earth to the sun, is shown; also a curve of the relative frequency of the direct type. The frequency of the inverse type is found by turning this curve over on the long axis. The dates at the top of the diagram are the mean dates of the beginning of the ephemeris for the same period during the years 1841–1894, and therefore identify average points of occurrence on the D curve. The dates of transition

are such that the D type tends to prevail from about February 1 to April 20 and July 15 to October 15, while the inverse type holds for the intervals April 20 to July 15 and October 15 to February 1. The tendency to form these types vigorously increases according to the relative height of the ordinates, and passes through places of indifference when the curve crosses the ecliptic. There is a force, therefore, striving to order the succession of maxima and minima, as found in the normal solar magnetic curve, in this proportion. At certain seasons of the year this succession is completely inverted relatively to other seasons. Since this normal curve is shown to be common to the magnetic and meteorological phenomena, it follows that such a force can properly have its seat only in a body outside the earth.

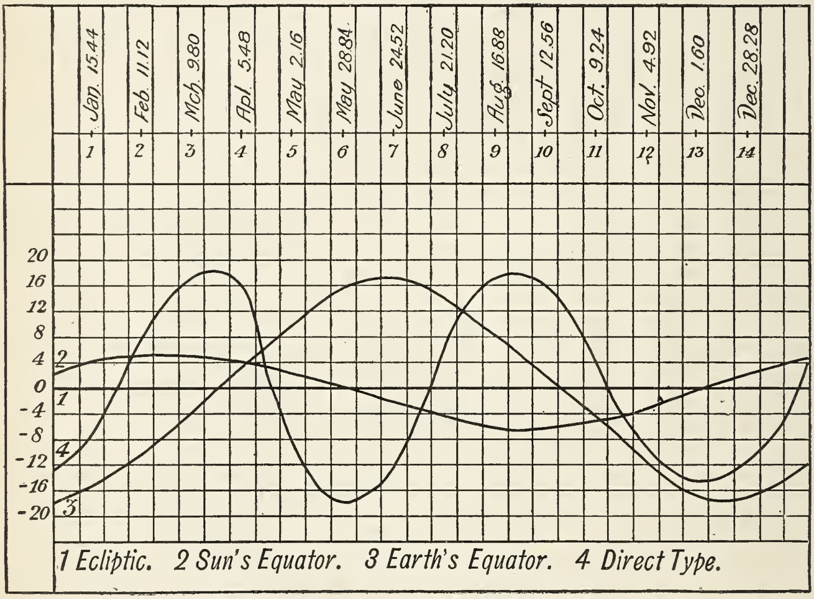


CHART 19.—Semiannual period of the direct type.

In order to see what relation this curve has to the astronomical triangle formed by the poles of the ecliptic K, sun's equator S, and earth's equator E, all four curves are projected on the plane of the ecliptic, with axis of the ecliptic passing through the center of the sun. Chart 20. It is perceived that the line of nodes perpendicular to K. S., is also the axis of the curve of the inverse type, and that K. S. is itself the axis of the curve of the direct type, the latter being omitted from the diagram. We conclude that such an outcome is not accidental, but has a cause in its relation to the axis of the sun, as defining the source producing the normal curve itself, and the phenomenon of inversion of the types. It would lead us too far from the immediate purpose of this chapter to give the solution of that point now, and it will therefore be reserved for another page. The analysis of a magnetic field, it may be

said in passing, emanating from a magnet placed with its axis on the average coincident with the axis of rotation of the sun, if its field by direct static action extends beyond the earth, should produce upon the earth's field exactly the phenomena described above. If this is so, then

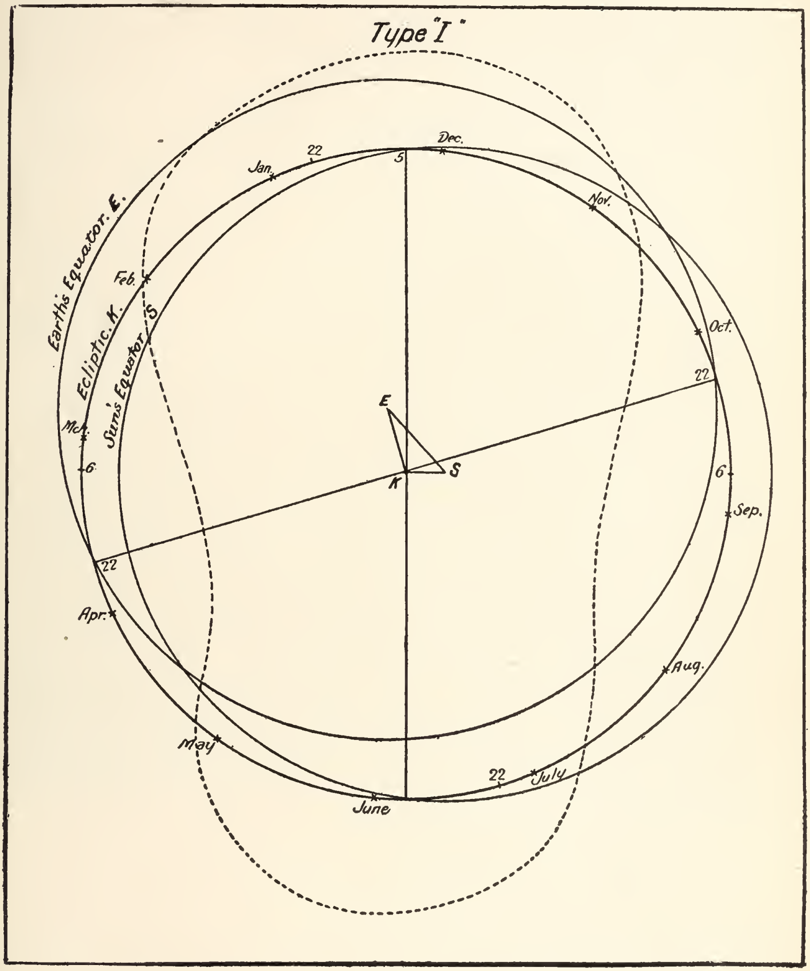


CHART 20.—Semiannual period of the inverse type, projected upon the ecliptic.

the theory of direct action of the sun as a magnet on the earth as a magnet will need no further defense. Whatever truth the theory of electric currents in the upper air may possess, whatever the final solution of the problem of radiation may be, the theory of direct action will merit respectful consideration among the premises.

SYNCHRONISM OF THE MAGNETIC AND THE METEOROLOGICAL ELEMENTS IN THE 26.68 DAY PERIOD.

We will now return to the immediate subject of finding the normal curve of solar action and of discussing synchronous variations of the magnetic and meteorological systems with which we began this chapter. The subdivision of the periods into two groups is now simply performed. As an example, part of the tabulations of the M P T system are reproduced (Table 22, 23). All the D periods and all the I periods in 1878 and 1882, respectively, are added together, and the algebraic sums placed at the bottom of the tables. It may be remarked that this is numerically a wasteful process, so far as obtaining large surviving residuals is concerned, because of the very loose formations of individual periods relatively to any normal type. There seems to be no way to separate immediately the normal curve, and it can in a preliminary investigation be obtained only by survival in a long series of observations. Tables 20, 22, 23 are constructed in precisely the same way for the European magnetic force, the northwest pressures and temperatures. On Tables 24, 25, 26 the annual results are collected together for the years 1878–1893, keeping the D and I groups by themselves. The sums are then taken for the given interval. In case no periodic impulse is embedded in the observations, if the period is not correct, if inversion of type is not a fact, then in so long a series of variations, if they are purely accidental, the algebra sums should be about zero. But by comparing the final D and I sums it is seen that they tend to accumulate in large plus values on certain days of the period, and in large minus values on others; also that this tendency is opposite on the same days in the D and I groups. This is true of each of the three elements compared. The rapid succession of maxima and minima points on the resulting curve constitutes the chief difficulty in detecting it in every individual period, especially considering the relatively feeble action of the sun's magnetic field upon the convectional movements of the atmosphere.

TABLE 22.—*Variations of the northwest pressures for 1878 and 1882.*

[Units second decimal, inches.]

	1	2	3	4	5	6	7	8	9	10	11	12	13
1878.													
Jan. 8.50	−34	+4	−32	−6	+23	+13	+8	−7	−15	−12	−8	−5	+6
Feb. 4.18	−43	−39	−15	−7	+7	+19	−9	−13	−4	−16	+3	0	+17
Mar. 2.86	+12	−1	−35	−23	−13	−53	−41	−33	−33	−1	−3	+20	−1
Mar. 29.54	+14	+35	+44	+27	+29	+14	+12	+8	−4	−39	−51	−7	−30
Apr. 25.22	+4	+8	+5	−13	−16	−12	−34	−8	−6	−24	−42	−12	+2
May 21.90	−9	−39	−11	+1	+2	+5	+9	+4	+5	−2	−2	−16	+2
June 17.58	−10	−7	+5	+9	+1	+11	−2	−2	+8	+1	−10	−23	−3
July 14.26	−21	−11	−3	−10	+6	+15	+26	+22	+14	+3	−17	−6	+13
Aug. 9.94	+6	+15	+1	−8	−15	+12	+15	−9	−5	+1	−12	−13	−18
Sept. 5.62	+5	+3	−11	+7	+33	+47	+25	+3	+2	+2	+5	+2	−2
Oct. 2.30	+19	+23	+23	−16	+2	−15	+14	−39	+8	−12	−27	−26	−37
Oct. 28.98	−20	+17	+29	−23	+34	+25	+25	−19	−10	+35	+38	+1	−19
Nov. 24.66	+17	−18	−17	−20	+10	+20	−2	−24	−43	−7	+1	+11	−8
Dec. 21.34	−7	−8	+41	+13	−6	+7	−3	−16	−12	−8	+12	+33	+47
Mean......	16	16	19	13	13	19	16	15	12	12	16	13	15
D........	+44	+76	+57	+10	+39	+58	+66	−37	+1	−48	−85	−44	−87
I........	−111	−94	−33	−79	+48	+50	−23	−96	−96	−31	−28	+3	+56
1882.													
Jan. 14.90	−21	+31	+13	−1	−6	−20	+12	+44	+28	−9	−44	−15	−5
Feb. 10.58	−21	−32	+9	0	−11	+2	+37	−9	+30	−1	−1	+22	+20
Mar. 9.26	+36	+9	0	+6	−21	+15	+6	−41	−8	−3	−22	+16	+32
Apr. 4.94	−13	−24	−20	−27	−14	+8	−1	+20	+30	+33	+14	0	−7
May 1.62	−16	−10	−19	−16	−1	−16	−44	−35	−19	+2	+17	+19	+15
May 28.30	−1	−7	+9	−4	−11	+15	+21	+31	+22	−5	−8	−17	−9
June 23.98	−12	+1	+8	−1	−5	−19	−16	+1	+5	+4	+20	+1	−14
July 20.66	+20	+12	+4	−7	−17	−1	−1	−3	0	−3	−8	0	+4
Aug. 16.34	+3	−7	+4	−4	−9	−3	−9	−10	−18	−15	−19	−19	+15
Sept. 12.02	−11	+3	−6	−21	−21	−20	+9	+28	+21	+21	+16	+3	+5
Oct. 8.70	+2	+14	−40	−47	−15	−26	−32	−3	0	+29	+15	+17	−2
Nov. 4.38	−16	−12	−11	+11	−7	−39	−21	+6	+5	+6	−16	+11	+27
Dec. 1.06	+43	−3	−11	−3	+16	+51	+8	−32	−2	−21	−21	−11	+13
Dec. 27.74	+18	+1	+22	+30	+17	−6	+14	−3	+3	−29	−8	+27	−29
Mean......	17	12	13	13	12	17	17	19	14	13	16	13	14
D........	+6	+19	+2	−37	−66	−58	+37	+6	+56	−7	−63	+51	+36
I........	+5	−43	−40	−47	−39	0	−54	−12	+41	+16	−2	+3	+29

TABLE 23.—*Variations of the northwest temperatures for 1878 and 1882.*

[Units of Fahrenheit degrees.]

	1	2	3	4	5	6	7	8	9	10	11	12	13
1878.													
Jan. 8.50	−1	+5	−1	+3	−1	−6	−6	−2	0	+1	+4	+3	+2
Feb. 4.18	+5	+8	+7	+3	−4	−9	−8	+2	−5	−2	−1	−3	−6
Mar. 2.86	−2	+3	+4	+5	+3	+8	+5	+2	+2	−4	−2	−3	+3
Mar. 29.54	−5	−4	−3	+1	0	+2	+2	−1	+4	+4	+1	−5	−6
Apr. 25.22	+3	+4	+8	+10	+8	+4	+5	−2	−8	0	+5	+7	+3
May 21.90	−1	+1	+3	+2	0	−3	−1	−1	−4	−2	+2	+2	0
June 17.58	+3	+4	+1	+1	+1	+4	+3	+4	−5	−1	+6	+5	−3
July 14.26	+7	+10	+3	+3	+5	+4	0	−1	−2	−2	0	0	−5
Aug. 9.94	−4	−2	−2	−1	−2	−4	−7	−6	−2	0	+1	+2	+6
Sept. 5.62	+2	+1	+6	0	−6	−12	−12	−7	0	+1	0	−1	+2
Oct. 2.30	+3	0	+1	+1	+4	−1	−5	−1	+2	+5	+3	+12	+5
Oct. 28.98	−8	−6	−12	−3	+1	−5	−1	+2	+8	0	−4	−1	+5
Nov. 24.66	−4	−9	+2	+1	+1	0	+1	+5	+12	+10	+7	+2	−2
Dec. 21.32	−7	−7	−13	−10	−1	−2	−3	−1	−1	0	−3	−20	−24
Mean......	4	5	5	3	3	5	4	3	4	2	3	5	5
D........	−4	−5	+2	+1	−4	−15	−22	−15	+4	+10	+5	+9	+7
I........	−5	+13	+2	+15	+13	−5	−5	+8	−3	0	+14	−8	−27
1882.													
Jan. 14.90	−7	−17	+3	−6	0	+5	−12	−21	−20	+1	+3	−14	−16
Feb. 10.58	+13	+7	+5	+18	+9	−24	−22	−18	−26	−9	−18	−16	−9
Mar. 9.26	−11	−4	−4	+4	+9	+7	+6	+10	−9	−7	−9	−16	−4
Apr. 4.94	+1	+2	+1	+3	−1	−3	−2	−3	−4	−1	+5	+5	+4
May 1.62	+4	+11	+8	+1	+2	+4	+1	+3	−1	−4	0	+2	+4
May 28.30	+5	+2	+1	0	−4	−6	−2	+4	+8	+8	+6	+1	−1
June 23.98	−8	−8	−6	−4	+1	+2	+1	+1	+3	0	+2	+3	+3
July 20.66	0	−2	+5	+6	+5	+2	+2	−5	+1	+3	+1	+1	+4
Aug. 16.34	+1	+2	−2	+1	0	+4	+4	+4	+6	0	+10	−4	−7
Sept. 12.02	0	+5	+13	+6	−1	−6	−11	−9	−7	−7	−2	+6	+10
Oct. 8.70	−9	−6	−2	0	+5	+2	−4	−3	−6	−3	+4	+4	+3
Nov. 4.38	+7	+8	+3	+1	−3	−3	−11	−16	−7	+5	+7	+1	+5
Dec. 1.06	0	+11	+5	−15	−24	−19	0	+2	−2	+1	−5	−16	−21
Dec. 27.74	+6	+6	−3	−3	−6	−8	−21	−12	−6	−11	−6	+4	+32
Mean......	5	6	4	5	5	7	8	8	8	4	6	7	9
D........	−7	−7	+10	+20	+16	−20	−60	−49	−68	−36	−18	−36	+9
I........	+9	+24	+17	−8	−24	−23	−11	−14	−2	+12	+16	−3	−2

TABLE 22.—*Variations of the northwest pressures for 1878 and 1882.*

[Units second decimal, inches.]

14	15	16	17	18	19	20	21	22	23	24	25	26	27	M. P. T.
+26	+2	−25	+10	−9	−1	−6	+2	+13	−8	+9	+43	+23	−9	I
+13	−43	−32	−15	+6	+26	+19	+42	+35	−10	−9	−16	−17	......	I
+30	+41	+14	+26	+19	+20	+18	+5	+31	+2	−40	−7	+27	+24	I
−6	+16	+13	+5	+5	+12	−39	−10	+6	−21	−20	−11	−5	+17	D
+29	+34	+35	+38	+25	+13	−3	−2	+1	−21	−35	+2	+21	......	I
+21	+21	+12	+2	−32	−12	+8	+1	+4	+14	+7	+5	+3	0	I
+18	+15	+4	+10	+3	−5	−5	−4	−5	+4	−10	−5	+8	+8	I
+6	−4	−12	−6	−2	−2	−3	−3	−4	−1	+3	0	−2	......	I
−5	+7	+24	−14	−6	+12	+17	−4	−7	+4	+10	+2	−11	+1	D
−20	−2	+15	−23	0	+5	+11	+51	+16	−22	−36	−55	−42	−16	D
−34	+7	+17	−8	−62	−10	+8	−3	+19	+35	+65	+48	−3	......	D
−7	−11	+14	+16	−8	−3	+8	−19	−7	−34	−5	−9	−46	−5	I
−30	−17	−40	−10	+31	+47	+18	−6	+2	+25	+36	+33	−2	−7	I
+43	+44	−23	−27	+8	−18	−16	−13	−27	−14	+13	−2	−18	−33	I
21	19	20	15	15	13	13	12	13	15	21	17	16	12	15.4
−65	+28	+69	−40	−63	+19	−3	+34	+34	−4	+19	−16	−61	+2	....
+149	+82	−53	+44	+41	+65	+38	+3	+43	−43	−31	+44	−3	−22	....
+24	+36	−9	−32	−5	+2	+5	−4	−5	−26	+20	+5	+2	−9	D
+17	+3	−2	−34	−34	−32	−1	+14	−40	−7	+22	+45	+16	−8	D
+27	+36	−25	−34	+6	−34	−18	+36	+11	−16	−5	−23	+1	......	D
−27	−12	−24	−27	−18	−2	−1	−6	0	+10	+29	+42	+22	+14	I
+10	+19	+10	+3	−22	+4	+21	+15	+23	+9	−2	−11	0	+7	I
+9	0	−13	−6	+10	−3	−23	−22	+4	−13	+2	+7	+6	......	I
−11	−17	−4	−10	−1	+13	+22	+2	−17	+5	+4	+12	+9	+21	I
+7	0	−2	+6	+12	+10	+15	+14	−5	−19	−26	−22	−8	+6	I
+13	+18	+13	−6	+7	+18	+12	+11	−2	+4	+7	+4	−3	−15	D
+11	−23	−24	−6	+9	+15	+8	+6	+9	−1	−2	−3	−20	......	D
+12	+9	−6	−2	+9	+7	−3	−12	−43	−18	+32	+51	+40	0	D
+19	+7	−8	+2	−22	+7	+10	−2	+8	+6	+7	+23	+12	−3	I
+45	+10	−26	−36	−39	−22	−12	−4	−19	+10	+11	+26	+37	......	I
−7	+8	−61	−4	−5	−2	−8	−8	−1	+20	−3	−8	+23	+26	D
17	14	16	15	14	12	11	11	13	12	12	20	14	8	14.2
+97	+87	−114	−118	−13	−26	−5	+43	−71	−44	+71	+71	+59	−6	....
+52	+7	−67	−68	−80	+7	+32	−3	−6	+8	+25	+77	+78	+45	....

TABLE 23.—*Variations of the northwest temperatures for 1878 and 1882.*

[Units of Fahrenheit degrees.]

14	15	16	17	18	19	20	21	22	23	24	25	26	27	M. P. T.
+3	−8	+2	−3	−5	+2	−6	−6	−2	−1	−2	−1	−3	−2	I
−3	+2	+3	+3	+1	−5	−6	−6	−4	+3	+5	0	+2	......	I
+2	−2	0	+5	+5	+5	+3	+9	+4	−5	+4	+6	−10	−12	I
+1	−2	−6	−5	−3	+3	+7	+7	+2	+6	+3	+3	+1	+3	D
−2	−7	−7	−12	−9	−6	−3	−3	−1	−3	−6	−4	−6	......	I
−2	0	+2	0	−1	−1	+1	+1	+1	−2	−3	−2	−4	+1	I
−9	−4	0	+1	−1	+4	+2	0	+2	−2	0	+4	+6	+9	I
−4	−4	−3	−3	−3	0	+4	+3	+4	+4	+4	+6	+3	......	I
+5	+3	−4	−5	+2	0	+3	+4	+6	+6	+3	+3	+7	+7	D
+7	−3	−7	−6	−6	0	0	+5	−5	+3	+8	+9	+11	+5	D
+2	−4	−8	−1	+6	+8	−8	−2	−4	−7	−12	−19	−14	......	D
0	+2	+2	−2	+1	+4	+3	+7	+9	+4	+5	+9	+8	+4	I
+3	+9	+5	+6	0	−4	−2	−1	+3	−9	−14	−9	−7	+6	I
−17	−13	−6	+12	+5	−7	−2	0	+8	+7	−3	−9	−6	0	I
4	5	4	5	3	4	4	4	4	4	5	6	6	5	4.2
+15	−6	−25	−17	−1	+11	+2	+14	−1	+8	+2	−4	+5	+15	....
−29	−25	−2	+7	−7	−8	−6	+4	+24	−4	−10	0	−17	+6	....
−23	−5	+3	+4	+7	+6	+12	+12	+18	+11	+3	+2	+10	+17	D
+1	+7	+5	+20	+20	+17	+13	+12	+9	−12	−23	−18	−3	−6	D
−14	−8	+3	0	−4	+11	−11	−7	+12	+12	+15	+6	+7	......	D
+2	0	+4	−2	−2	+1	+1	0	−2	−1	−1	−4	−2	−6	I
+6	+9	+5	+3	−3	−13	−17	−17	−8	−1	+1	−1	−2	+3	I
0	+4	+1	+1	−1	−4	−9	−13	−14	−10	−7	−7	−6	......	I
+4	+4	+1	−3	−9	−7	−7	−3	−5	−5	−4	−6	−5	−4	I
+6	+7	+7	+7	+1	−2	−4	0	0	−3	0	−2	−1	0	I
−8	−10	−7	−4	−1	+2	−2	0	+2	−1	+1	+2	+2	+1	D
+10	+4	−1	−7	−7	0	+6	+6	+8	+8	+5	−1	−5	......	D
+2	+5	+7	−1	−1	+6	−1	−2	+1	−5	−4	−4	+1	+6	D
+8	+9	+9	+7	+2	−5	−7	−3	−4	+1	−3	0	+9	+3	I
−10	+9	+14	+15	+12	+6	+1	+4	+6	+6	+9	+5	+4	......	I
+11	+11	+11	−2	−2	+7	+13	−9	−14	−20	−18	−13	−12	−4	D
8	7	6	5	5	6	7	6	7	7	7	5	5	4	6.2
−21	+4	+21	+10	+12	+49	+30	+12	+36	−7	−21	−26	−14	+14	....
+16	+42	+41	+28	0	−24	−42	−32	−27	−13	−5	−15	−3	−4	....

TABLE 24.—*Summary of horizontal component σ.* (System M. P. T.)

DIRECT TYPE.

Year.	1	2	3	4	5	6	7	8	9	10	11	12	13
1878...	− 218	−125	−207	−117	+ 51	− 221	+ 60	+ 70	+ 155	+ 80	+213	+ 272	+ 151
1879...	+ 176	+ 5	+194	+183	+ 235	+ 329	− 83	−235	− 88	+ 334	+126	+ 115	− 86
1880...	+ 256	+315	+237	+347	+ 171	+ 403	+228	− 30	+ 92	+ 223	+201	+ 238	+ 293
1881...	− 344	+ 8	+ 37	−243	− 26	− 210	−185	−105	− 77	+ 74	+244	+ 248	+ 647
1882...	− 213	−316	+ 70	+445	+ 358	+ 130	− 68	− 37	+ 329	+ 594	− 52	− 31	+ 76
1883...	+ 152	+506	+ 74	−246	− 51	− 114	+108	+239	+ 287	+ 337	−451	− 406	+ 117
1884...	+ 360	+265	+201	−140	− 664	− 571	−361	−367	− 127	− 158	+ 85	+ 131	+ 286
1885...	+ 375	+295	+195	+281	+ 459	+ 412	−529	−361	− 632	− 431	−762	− 491	+ 192
1886...	+ 193	−527	+609	−485	− 55	+ 385	+331	+298	+ 281	+ 561	+750	+ 706	+ 573
1887...	− 105	−400	−423	−470	− 430	− 95	+ 69	+172	+ 46	− 31	− 87	+ 160	+ 5
1888...	+ 648	+326	−192	+ 1	− 236	+ 12	− 98	−161	− 145	− 180	+ 31	+ 134	− 104
1889...	+ 96	−123	−146	+ 14	+ 208	+ 130	− 49	− 52	+ 157	+ 198	− 53	+ 207	+ 357
1890...	+ 188	+ 61	+298	+291	+ 349	+ 175	+240	+275	+ 142	+ 23	+ 93	+ 199	+ 184
1891...	− 170	+ 84	− 54	−230	+ 252	+ 336	− 6	+230	+ 325	+ 191	− 11	+ 66	+ 42
1892...	− 412	−240	−210	−236	− 50	+ 180	+360	+178	+ 136	+ 376	+428	+ 500	+ 449
1893...	+ 25	+214	+610	+340	+ 561	+ 421	+458	+308	+ 291	+ 308	+158	+ 363	− 67
D...	+1007	+348	+ 75	−265	+1132	+1698	+475	+422	+1172	+2499	+913	+2411	+3115

INVERSE TYPE.

Year.	1	2	3	4	5	6	7	8	9	10	11	12	13
1878...	+ 214	+ 468	+ 545	+ 22	− 131	− 248	+168	− 304	− 202	+ 118	+ 90	+ 99	+ 411
1879...	+ 183	+ 255	+ 123	+ 32	+ 109	− 116	−352	− 226	− 247	− 26	− 165	− 245	− 89
1880...	+ 172	− 53	+ 171	− 90	+ 83	+ 98	+178	+ 142	− 130	+ 219	− 75	− 59	+ 25
1881...	+ 474	+ 1	+ 127	+ 611	+ 511	− 246	+234	− 265	− 180	− 416	− 518	+ 39	+ 117
1882...	+ 180	+ 164	+ 450	+ 474	+ 415	+ 274	+387	+ 571	+ 561	+ 690	+ 539	+ 427	+ 397
1883...	+ 52	+ 259	+ 345	+ 379	+ 304	+ 253	+129	+ 169	− 148	+ 1	− 177	+ 31	− 147
1884...	+ 465	+ 274	+ 327	+ 453	− 116	− 166	−265	+ 353	+ 742	+ 223	− 575	− 314	+ 25
1885...	+ 626	+ 20	+ 135	+ 273	− 356	− 175	+ 99	+ 157	− 85	− 29	+ 37	− 26	+ 94
1886...	+ 337	− 283	− 359	− 135	− 87	− 103	− 74	+ 135	+ 219	+ 363	+ 64	+ 215	+ 383
1887...	− 166	− 280	− 278	− 31	− 79	+ 71	+ 65	+ 392	+ 524	+ 413	+ 280	− 145	− 421
1888...	+ 160	+ 36	+ 348	− 136	− 357	− 277	−192	+ 269	+ 418	+ 274	+ 186	− 628	− 660
1889...	+ 155	+ 44	− 30	− 54	+ 114	+ 97	+121	+ 214	+ 95	− 70	− 92	+ 143	+ 165
1890...	− 2	+ 280	+ 242	+ 159	+ 217	+ 270	−130	+ 100	+ 118	+ 146	+ 326	+ 285	+ 57
1891...	+ 182	+ 148	− 595	− 144	− 156	− 34	+ 16	− 38	+ 330	− 384	− 699	− 236	− 67
1892...	− 346	− 341	− 341	− 26	− 589	− 349	+121	+ 497	− 75	+ 170	+ 380	+ 44	− 19
1893...	+ 216	+ 323	+ 295	+ 484	0	+ 144	− 87	+ 10	− 14	+ 68	− 229	− 125	− 290
I....	+2902	+1315	+1505	+2271	− 118	− 507	+418	+2176	+1926	+1760	− 628	− 495	− 19
D-I....	−1895	− 967	−1430	−2536	+1250	+2207	+ 57	−1754	− 754	+ 739	+1541	+2906	+3134

TABLE 25.—*Summary northwest pressure variations.* (System M. P. T.)

DIRECT TYPE.

Year.	1	2	3	4	5	6	7	8	9	10	11	12	13
1878...	+ 44	+ 76	+ 57	+ 10	+ 39	+ 58	+ 66	− 37	+ 1	− 48	− 85	− 44	− 87
1879...	− 6	− 54	−115	+ 4	− 39	+ 10	− 26	+ 69	+ 64	− 20	− 36	− 68	+ 19
1880..	− 94	− 23	+ 15	− 17	− 34	+ 21	+ 62	+ 74	+ 64	+ 1	− 26	− 23	+ 15
1881...	− 9	− 5	− 30	+ 16	+ 41	+ 13	+ 7	+ 3	+ 24	− 9	− 34	+ 10	+ 18
1882...	+ 6	+ 19	+ 2	− 37	− 66	− 58	+ 37	+ 6	+ 56	− 7	− 63	+ 51	+ 36
1883...	− 1	+ 82	− 43	− 10	+ 15	+ 3	− 16	+ 60	+ 64	+ 33	+ 27	+ 59	+ 19
1884...	+ 13	− 7	+ 45	− 26	+ 48	− 49	+ 26	− 11	+ 22	+ 36	+ 68	+ 8	− 14
1885...	+ 31	− 27	− 70	−107	+ 2	− 9	+ 27	− 13	− 10	+ 31	+ 11	+ 25	+ 45
1886...	+ 34	− 18	− 97	− 62	+ 47	+ 33	+ 41	− 16	+ 81	+ 14	− 41	− 1	− 20
1887...	+ 85	− 31	− 50	− 15	− 9	+ 32	+ 47	+ 19	+ 22	+ 6	− 5	+ 11	− 36
1888...	−118	− 30	− 1	+ 21	+ 1	− 44	+120	+ 86	+ 57	− 23	− 37	− 32	− 88
1889...	− 34	− 24	− 84	−122	− 42	− 86	− 59	+ 82	+ 154	+ 92	+ 37	+ 46	+ 15
1890...	+ 4	+ 13	− 21	+ 73	+ 32	− 23	− 55	− 51	+ 15	− 1	+ 57	+ 56	− 50
1891...	− 3	0	+ 13	0	− 31	− 69	− 45	+ 15	+ 16	+ 57	+ 24	− 47	− 39
1892...	+ 8	+ 30	+ 17	+ 69	+ 93	+ 50	− 27	− 17	− 22	+ 11	+ 38	+ 18	− 13
1893...	− 36	+ 7	− 27	− 8	− 4	− 25	+ 24	+ 64	+ 70	+ 6	+ 23	+ 10	+ 11
1894...	+ 20	− 42	− 69	+ 13	+ 10	+ 88	+ 65	+ 71	+ 78	+ 28	− 32	− 32	− 94
D...	− 56	− 34	−458	−198	+103	− 55	+294	+ 404	+ 756	+207	− 74	+ 47	−353

TABLE 24.—*Summary of horizontal component σ.* (System M. P. T.)

DIRECT TYPE.

14	15	16	17	18	19	20	21	22	23	24	25	26	27
+145	+106	+225	+126	+150	−98	−131	−3	−1	+3	−54	−118	+23	−32
+7	−466	−292	−213	+338	+462	+150	+61	−124	+156	−121	−316	+91	+148
+295	+287	+184	+109	−6	−39	−4	−12	−88	+165	−12	+195	+63	+82
+164	+32	+338	+444	+296	−171	−254	−31	+63	+219	+386	+99	−54	+100
+273	+461	+396	+548	+366	+399	+424	+365	−69	+172	+304	−135	+106	+290
+204	+109	+287	+480	+14	−30	+144	+163	+458	+50	−312	+195	−189	−83
+569	+343	+492	+575	+470	+209	+236	+538	+43	−205	−179	−651	−416	−136
+152	−71	+485	+558	+443	−348	−412	+87	+383	+343	+97	+481	+365	−58
+599	+315	+581	+356	+709	+298	−520	−889	−761	−468	−278	−6	−55	+32
+79	+308	+206	+235	+60	−60	+285	+68	+219	+334	+501	+350	+37	+48
−90	−106	−25	+265	−121	−156	−89	−341	+85	+289	+340	+267	+444	+524
+144	+274	+153	+171	+270	+205	+219	−279	−406	−262	−382	−109	−120	+134
−41	−393	−155	−203	−42	−290	−243	+116	+30	−20	−72	−4	+47	−36
+157	−40	+103	+5	+68	−139	−198	−46	−94	+304	+146	+10	+70	−122
+558	+42	+330	+603	−336	−356	−38	−18	−115	−472	−455	−271	+58	+188
−177	−383	+149	+142	+264	+154	+217	+142	−25	−428	−323	−268	+285	−10
+3038	+818	+3457	+4201	+2943	+40	−214	−79	−402	+180	−414	−281	+755	+773

INVERSE TYPE.

14	15	16	17	18	19	20	21	22	23	24	25	26	27
−20	+83	−7	−31	+341	+546	−1	−38	−74	+19	−80	−102	+59	+209
−263	−286	−116	+171	+245	+463	+12	−285	−244	−150	+129	+276	+154	+248
−244	−258	−186	−24	−277	−347	−291	−333	−381	−421	−161	+65	+386	+540
+213	−42	+241	−312	−358	−433	+47	+497	+370	+530	+477	+317	+2	+1
−464	−322	−672	−829	−713	−1028	−603	−698	−671	−273	+302	−125	+419	+448
+15	+246	+111	−353	+833	+291	−541	+150	−19	+6	+99	+233	+371	+220
+13	+508	+667	−364	−744	−438	+60	+53	−131	+173	+324	+308	+266	+394
+330	+292	−494	−520	+23	+97	+98	+266	+66	+21	+208	+349	+42	+140
+394	+347	−12	−265	−111	+75	+187	−2	−53	−175	−30	+170	+322	+265
−141	−211	−385	−25	−58	+50	+324	+365	+640	+384	+595	−217	−585	−127
−410	−228	−243	−157	+263	+358	+238	+102	+198	+221	+482	+48	+151	+27
+246	+383	+339	+302	+145	−6	−15	−374	−152	−449	−228	−303	+23	−13
−211	+140	+162	+67	−1	−323	−57	+37	−183	+53	+257	+34	+339	+242
+128	+471	+382	−48	+192	−174	+8	+148	−54	−242	−204	+55	+144	−74
+712	+353	+172	+61	+230	+230	+499	+653	+329	+135	+388	+769	+790	−51
−413	−493	−475	−231	+51	+138	+261	+481	+421	+471	+66	−5	−48	+43
−115	+983	−516	−2558	−539	−1083	+226	+1022	+62	+303	+2624	+1872	+2835	+2512
+3153	−165	+3973	+6759	+3482	+1123	−440	−1101	−464	−123	−3038	−2153	−2080	−1739

TABLE 25.—*Summary northwest pressure variations.* (System M. P. T.)

DIRECT TYPE.

14	15	16	17	18	19	20	21	22	23	24	25	26	27
−65	+28	+69	−40	−63	+19	−3	+34	+34	−4	+19	−16	−61	+2
−35	−30	−16	−51	−66	−8	+52	+77	+17	+40	+63	−26	−44	−68
−15	+56	−41	−114	−78	−32	+67	+33	−1	−23	+56	+47	−12	+13
+25	−40	+5	−15	−28	−7	+33	+15	−20	−77	−26	+47	+54	−12
+97	+87	−114	−118	−13	−26	−5	+43	−71	−44	+71	+71	+59	−6
−27	+35	+78	−4	−112	−124	−40	−21	−84	−78	+5	+62	+5	−19
+3	+32	+7	−37	−41	+1	0	+4	+8	−4	+2	−82	−51	+7
−13	−12	−10	+12	−7	−62	+73	+74	+31	−19	+2	−14	+58	+16
+44	−32	+91	−51	−43	−16	−46	+87	+4	−13	−30	−72	+22	+30
−52	+68	−10	+15	−12	−18	−31	+16	−30	−68	+18	+79	−27	+16
−27	+27	+50	+20	−15	+2	−11	+94	+93	+59	+79	+57	−37	−73
−58	+40	+31	+61	+29	−15	−2	+32	+50	+7	−27	−20	−63	−39
+13	−28	−22	−60	−67	+8	+22	+13	−38	−18	+109	+55	−5	−24
−18	+26	−40	−11	−1	+21	+36	+55	+22	−4	−31	−13	+36	+41
−48	+15	+18	−43	−95	−62	−44	−43	−35	−13	+19	+1	+40	+47
−7	−14	−33	−48	−39	−158	+18	+83	+13	−54	+27	+6	+20	+69
−91	−60	−41	−87	+30	+46	+55	+3	−20	+70	+81	−39	−31	+39
−274	+198	+22	−571	−621	+431	+174	+599	−27	−243	+437	+143	−37	+39

Table 25.—*Summary northwest pressure variations.* (System M. P. T.)—Continued.

INVERSE TYPE.

Year.	1	2	3	4	5	6	7	8	9	10	11	12	13
1878...	—111	— 94	— 33	— 79	+ 48	+ 50	— 23	— 96	— 96	— 31	— 28	+ 3	+ 56
1879...	— 41	+ 78	+ 38	+ 21	+ 15	— 25	— 65	— 98	— 154	— 71	+ 53	+ 22	+ 27
1880...	— 16	— 62	+ 1	— 33	— 22	— 29	—108	— 76	— 25	+ 39	+ 7	+110	+108
1881...	0	— 7	— 7	+ 46	+ 21	— 90	— 31	— 73	— 63	+ 45	+ 10	+ 37	+ 38
1882...	+ 5	— 43	— 40	— 47	— 39	0	— 54	— 12	+ 41	+ 16	— 2	+ 3	+ 29
1883...	— 33	+ 99	+ 84	— 10	+ 50	+ 23	— 86	— 194	— 111	— 39	— 9	— 9	— 60
1884...	— 55	— 58	— 33	— 62	+ 45	— 24	— 15	+ 1	+ 25	— 10	— 10	— 13	+ 10
1885...	+ 14	+ 43	+ 35	+ 39	— 16	— 51	— 22	+ 8	— 2	+ 13	— 16	— 7	+ 48
1886...	— 57	— 80	— 64	— 48	— 19	+ 33	+ 31	+ 22	— 42	+ 10	+ 28	+ 45	— 8
1887...	+ 44	+ 26	+ 1	+ 16	+120	+150	+ 30	— 123	— 134	— 25	— 88	— 95	+ 41
1888...	+ 25	+ 18	— 3	— 55	+ 52	+ 97	+ 71	+ 51	+ 41	+ 71	+ 32	+ 19	— 55
1889...	— 31	—126	— 62	— 48	+ 37	+ 45	+ 88	+ 47	0	— 1	— 44	— 41	— 4
1890...	— 71	+ 66	+ 69	+ 43	+ 46	+105	+ 57	+ 12	+ 22	+ 36	+ 33	+ 14	— 17
1891...	— 3	+ 2	+178	+ 73	— 17	— 52	—104	— 118	— 99	— 69	— 15	+ 33	+ 6
1892...	+ 20	— 46	+ 51	+ 32	— 43	— 22	+ 15	— 98	— 34	— 34	+ 40	— 46	+ 29
1893..	+ 77	+ 12	+ 41	+ 43	+ 44	— 54	— 65	— 62	— 21	+ 46	— 57	— 61	— 1
1894...	— 23	+ 23	— 62	— 35	— 89	+ 15	+ 1	— 20	— 59	— 25	+ 53	+ 57	— 60
I ...	—256	—149	+194	—104	+233	+171	—280	— 828	— 711	— 29	— 13	+ 71	+187
I—D..	—200	—115	+652	+ 94	+130	+226	—574	—1233	—1467	—236	+ 61	— 24	+540

Table 26.—*Summary northwest temperature variations.* (System M. P. T.)

DIRECT TYPE.

Year.	1	2	3	4	5	6	7	8	9	10	11	12	13
1878...	— 4	— 5	+ 2	+ 1	— 4	—15	— 22	— 15	+ 4	+ 10	+ 5	+ 9	+ 7
1879...	— 7	— 3	— 10	+18	+ 6	+ 3	— 11	— 9	— 20	+ 7	+ 14	+ 8	+ 9
1880...	+36	+ 35	+ 17	+ 7	+ 8	— 1	— 23	— 38	— 21	— 23	— 1	— 2	+ 9
1881...	+33	+ 34	+ 32	— 9	— 21	— 5	— 2	— 4	— 18	— 16	— 6	—11	—13
1882...	— 7	— 7	+ 10	+20	+ 16	—20	— 60	— 49	— 68	— 36	— 18	—36	+ 9
1883...	—35	— 9	+ 6	+ 9	— 3	+22	+ 8	— 16	— 21	— 29	— 38	—21	—24
1884...	+ 7	— 1	— 14	+ 4	— 22	+ 5	— 6	— 11	— 39	— 21	— 12	+25	— 2
1885...	—34	— 5	— 3	+ 7	— 34	—33	— 13	— 26	— 45	— 23	— 30	—25	—27
1886...	—13	+ 4	+ 33	+31	+ 10	+17	+ 25	+ 5	— 22	— 12	— 14	—24	—28
1887...	—26	+ 14	— 1	— 1	— 5	— 3	— 11	— 34	— 12	— 16	— 7	— 6	+ 2
1888...	—29	— 50	— 34	—32	— 15	—18	— 40	— 26	— 18	+ 14	+ 27	+21	+36
1889...	+ 4	+ 3	+ 11	— 1	— 11	+ 5	+ 9	— 9	— 31	0	+ 12	+21	+16
1890...	+39	+ 29	+ 36	+16	+ 35	+31	+ 35	+ 30	+ 7	+ 31	+ 11	— 5	— 4
1891...	— 6	— 3	— 23	—32	— 20	— 3	— 26	— 34	— 21	— 6	+ 15	+34	+ 9
1892...	—35	— 25	— 32	—30	— 35	—25	— 12	+ 3	+ 8	+ 7	+ 1	+12	+17
1893...	—28	— 19	— 22	—27	— 5	—11	0	— 22	— 1	+ 9	+ 3	+ 7	+ 7
1894...	+32	+ 39	+ 33	0	— 1	— 5	— 17	— 2	+ 10	+ 24	+ 17	+15	+18
D...	—73	+ 31	+ 41	—19	—101	—56	—166	—257	—308	— 80	— 21	+22	+41

INVERSE TYPE.

Year.	1	2	3	4	5	6	7	8	9	10	11	12	13
1878...	— 5	+ 13	+ 2	+15	+ 13	— 5	— 5	+ 8	— 3	0	+ 14	— 8	—27
1879...	—13	— 41	— 7	— 7	+ 9	+ 1	+ 12	+ 18	+ 19	+ 48	— 7	+ 5	+18
1880...	—25	+ 13	+ 24	+ 7	+ 13	+11	+ 22	+ 32	+ 17	+ 12	+ 13	+ 9	+ 1
1881...	— 8	— 12	— 22	+10	+ 26	+16	— 21	+ 8	+ 1	+ 23	— 1	—12	— 3
1882...	+ 9	+ 24	+ 17	— 8	— 24	—23	— 11	— 14	— 2	+ 12	+ 16	— 3	— 2
1883...	+ 5	— 4	+ 8	+17	+ 19	+34	+ 13	+ 11	— 12	— 6	+ 15	+ 1	— 5
1884...	—15	— 33	— 36	—19	— 35	—34	— 15	— 14	— 2	+ 2	+ 6	+ 3	+ 8
1885...	+27	+ 20	+ 29	+43	+ 28	— 8	— 27	— 27	— 15	— 8	— 11	—16	—46
1886...	+23	+ 17	+ 15	+25	+ 17	+22	+ 5	+ 12	+ 16	+ 14	— 7	+ 6	0
1887...	— 2	— 12	— 23	—50	— 64	—38	— 25	— 41	+ 27	— 10	+ 18	+14	—35
1888...	—17	— 13	+ 10	—16	— 34	—24	+ 7	+ 14	+ 34	+ 29	+ 52	+34	+36
1889...	+ 5	— 1	+ 3	—19	+ 6	—17	— 30	— 15	— 4	+ 14	+ 22	+14	+39
1890...	— 6	— 24	— 44	—39	— 42	—26	— 7	+ 9	— 8	— 39	— 17	—17	+19
1891...	—16	— 49	— 82	—11	+ 22	+11	+ 16	+ 55	+ 40	— 1	— 15	—31	+10
1892...	— 5	+ 16	— 17	+12	+ 22	— 3	— 18	+ 8	+ 49	+ 26	+ 21	+26	+ 4
1893...	— 6	— 12	— 19	—15	— 23	+ 9	+ 6	0	— 21	— 21	— 5	— 3	—21
1894...	—21	— 14	+ 19	+24	+ 35	+13	— 9	— 3	+ 6	+ 8	— 15	+ 7	+ 9
I ...	—70	—112	—123	— 3	— 12	—61	— 87	+143	+142	+103	+ 99	+29	+ 5
D—I..	— 3	+143	+164	+12	— 89	+ 5	— 79	—400	—450	—183	—120	— 7	+36

TABLE 25.—*Summary northwest pressure variations.* (System M. P. T.)—Continued.

INVERSE TYPE.

14	15	16	17	18	19	20	21	22	23	24	25	26	27
+149	+82	—53	+44	+41	+65	+38	+3	+43	—43	—31	+44	—3	—22
+133	+38	—46	+88	+42	+20	—14	+37	+69	+44	—124	—76	—1	+1
+36	+51	—45	+35	+85	+87	+31	—25	—82	—29	—26	0	—38	+14
+15	+59	+19	+10	+6	+7	+25	—30	+13	—20	+14	+8	—4	0
+52	+7	—67	—68	—80	+7	+32	—3	—6	+8	+25	+77	+78	+45
—6	0	+33	—27	—42	—32	+87	—14	+9	+62	0	+29	+45	+80
+32	+51	+33	+63	+49	+7	—6	—52	—54	+40	+13	+55	—6	—44
+52	+17	—27	—1	—13	—41	—13	+19	+9	—5	—67	—27	—5	+2
+31	+2	+10	+4	—10	+10	+15	+22	+8	—55	+13	+53	+57	—19
+84	—53	—99	—77	—129	—89	—18	—35	—11	+48	—13	+3	+38	—3
—22	—51	+89	+32	—15	—22	—30	+5	+1	—65	—122	—100	—67	+18
—13	—39	—27	+12	+2	+61	+74	+30	+11	+45	+81	—52	—81	+21
—52	—127	—87	+13	+68	+80	+5	—76	+22	—34	—80	—3	—17	+4
+11	+40	+45	+46	+14	+21	+16	—72	—59	+45	—34	—10	—16	+15
+2	+57	+136	+66	+62	+51	+1	—46	—14	—2	—34	—64	—73	+13
+25	—15	—62	—47	—82	+23	+1	—10	+27	+61	+20	+37	+48	+41
+7	+60	+132	+81	—1	+6	+134	—20	—35	—75	—2	—17	—26	+12
+536	+179	—16	+280	—3	+261	+378	—267	—49	+25	—367	—43	—71	+178
+810	—19	—38	+851	+618	+692	+204	—866	—22	+268	—804	—186	+34	+139

TABLE 26.—*Summary northwest temperature variations.* (System M. P. T.)

DIRECT TYPE.

14	15	16	17	18	19	20	21	22	23	24	25	26	27
+15	—6	—25	—17	—1	+11	+2	+14	—1	+8	+2	—4	+5	+15
—6	+12	+30	+14	+44	+46	+31	—6	—15	—13	—20	—12	+9	—1
+22	+2	—4	+34	+30	—3	—25	—37	—41	—15	—22	—41	—16	+2
—32	—14	+1	+16	+10	+9	+13	+10	+35	+22	—12	—25	+20	+25
—21	+4	+21	+10	+12	+49	+30	+12	+36	—7	—21	—26	—14	+14
—24	—38	+7	+26	+29	+22	+10	+30	+28	—6	—20	+12	+24	+37
—7	—10	+15	+16	+1	+12	+6	+2	+21	+23	+16	+20	+6	—18
—27	—9	+12	+7	+44	+57	+17	+33	+58	+36	+23	+15	—15	—14
+5	+21	+36	+55	+32	+6	—28	—59	—35	—23	—21	—40	—21	—12
+11	—25	—16	—15	+9	+22	+9	+2	+6	+26	+17	+7	+7	—30
+17	+13	+22	+11	+23	+7	+10	+16	+4	+12	—28	—29	+1	—34
+13	—7	+6	+11	+14	+24	—4	+5	—23	—10	+14	+7	+20	—15
—35	—32	—22	—13	—13	—22	—44	—34	—12	—14	—20	—13	+18	+21
+14	—2	+23	+10	+17	—4	—13	—4	+12	+6	—3	—3	—13	—19
+6	+12	+16	+13	+9	+21	+15	+18	+21	+29	—3	+5	+20	—16
+6	—11	+10	+33	+26	+19	+13	+15	+7	—15	—33	—31	—37	—20
0	+6	0	+24	+13	+23	+10	0	—21	—44	—23	+8	+23	+9
—43	—84	+132	+235	+299	+299	+52	+17	+89	+15	—154	—149	+37	—56

INVERSE TYPE.

14	15	16	17	18	19	20	21	22	23	24	25	26	27
—29	—25	—2	+7	—7	—8	—6	+4	+24	—4	—10	0	—17	+6
—28	—41	—9	—11	—17	+7	—3	—1	—27	—18	+22	+36	+7	+16
+15	+6	—2	—2	—26	—27	—4	+15	+22	+32	—6	—10	+2	—12
—8	+4	+11	+19	+22	—1	0	—10	—25	—20	—16	—24	+3	+14
+16	+42	+41	+28	0	—24	—42	—32	—27	—13	—5	—15	—3	—4
+3	—3	—8	—8	—15	—6	+8	+21	+11	+5	+21	—8	—14	—16
—9	—11	+9	+30	+42	+40	+45	+37	+14	—7	+21	—3	—6	+2
—42	—50	—11	—15	+5	+21	+5	0	+9	+21	+18	—15	—21	—5
—3	+12	—11	—30	—33	—40	—8	+1	+5	+15	—9	—32	—11	+16
—10	+52	+48	+7	+30	+34	+31	+19	—14	+3	+10	+9	—9	—30
+12	+14	—22	—19	—20	—13	—3	—2	+9	+20	+18	0	—5	—20
+14	+14	+12	—15	—11	—11	—12	0	+24	—1	—6	+20	—17	—2
+27	+31	+3	—16	—43	—46	—21	+8	—22	—2	+29	+43	+45	+2
+8	+17	+13	—6	+1	—1	+3	+25	+8	—32	—15	+5	+4	—4
+9	+1	—7	—10	—10	—31	—11	0	+4	+3	+20	+15	+11	—13
—21	—11	+22	+19	+14	+16	+9	+26	+1	—12	+18	+17	—3	+14
—16	—34	—58	—55	—7	—22	—53	+11	+3	+43	+25	+17	+17	—12
—62	+18	+29	—77	—74	—112	—62	+122	+19	+33	+135	+55	+16	—48
+19	—102	+103	+312	+373	+411	+114	—105	+61	—18	—289	—204	+60	—8

Lest the criticism may be urged that this selection of groups approximately conforming to a normal curve would reproduce any curve adopted as the model, for a final collection the general law of Table 21 was applied rigorously throughout the same data, *wherein no selection is made by matching.* This is a *tour de force* and an excessive test of the period, the curve, and the deduced law, because it is applied mechanically through sixteen years of data in the magnetic force, the pressure and the temperature, right up to the transition dates, whereas in the periods near the penumbral dates there is likely to be an overlapping of the periodic form, even for some distance, or else a condition where the true normal form is not impressed vigorously upon the earth's field, so that the curves of observation may there be partly fortuitous. As our object is to establish a normal curve and period, the result derived from the general law is merely corroborative of the others. It will require a still further review of the observations to distinguish the best subdivision of the periods, because all the results given in this paper are such as came to hand without knowing what the physical law really was. On Table 27 are collected the various summations under the respective heads, which are self-explanatory after this recital of the procedure followed in the computations. These values are plotted as ordinates on the respective curves, which are plainly marked for intercomparison, charts 21, 22. In spite of many minor divergencies among these curves, the type is clearly discerned, and the adopted form of the normal curve is drawn at the bottom of the D and I type diagrams respectively. By comparison, these curves are found to be the same on inverting one of them. The conclusion is obvious that a typical normal curve underlies the entire system of magnetic and meteorological observations, and that the former precedes the latter in the sequence of cause and effect. (Compare Chart 9.)

CHART 21.—26.68 day solar period, direct type.
CHART 22.—26.68 day solar period, inverse type.

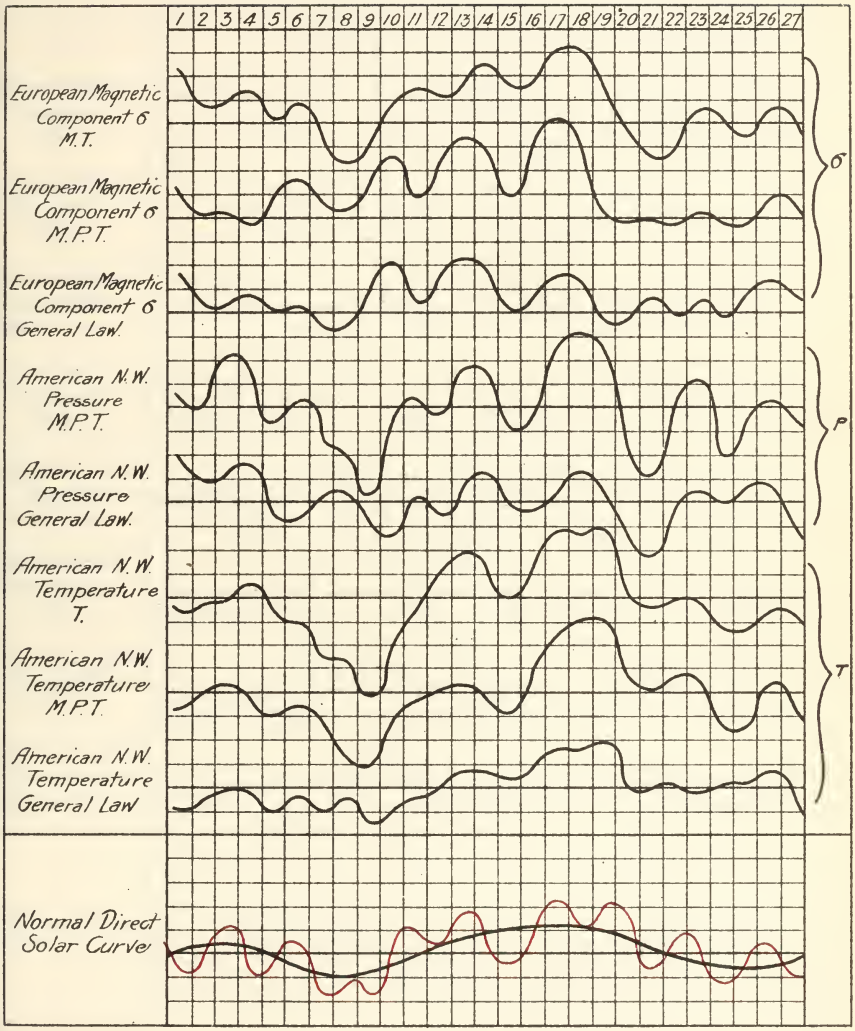

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
European Magnetic Component σ M.T.
European Magnetic Component σ M.P.T.
European Magnetic Component σ General Law.
American N.W. Pressure M.P.T.
American N.W. Pressure General Law.
American N.W. Temperature T.
American N.W. Temperature M.P.T.
American N.W. Temperature General Law
Normal Direct Solar Curve
σ
P
T

Chart 21.

TABLE 27.—*Determination of the normal solar curve.*

Period.	Direct type.								Inverse type.							
	European magnetic component σ.			American pressure.		Northwest temperature.			European magnetic component σ.			American pressure.		Northwest temperature.		
	M. T.	M. P. T.	Law.	M. P. T.	Law.	T.	M. P. T.	Law.	M. T.	M. P. T.	Law.	M. P. T.	Law.	T.	M. P. T.	Law.
1	+2164	+1007	+1554	+ 56	+333	- 71	- 73	- 85	+2184	+2902	+2355	+256	- 21	- 69	- 70	- 58
2	+ 761	+ 348	+ 398	+ 34	+210	- 3	+ 31	- 47	+ 714	+1315	+1265	+149	- 27	- 73	-112	- 34
3	+ 943	+ 75	+ 211	+458	+210	- 19	+ 41	- 1	+1333	+1505	+1369	-194	+ 54	- 65	-123	- 81
4	+1293	- 265	+ 584	+198	+324	+ 60	- 9	- 23	+ 505	+2271	+1422	+104	- 22	-110	- 3	- 27
5	+ 124	+1132	+ 119	-103	-137	- 63	-101	- 97	+ 872	- 118	+ 895	-203	-199	- 50	- 12	- 16
6	+ 706	+1698	+ 100	+ 55	-129	-107	- 56	- 67	- 200	- 507	+1089	-171	+ 13	- 8	- 61	- 50
7	- 808	+ 475	- 472	-294	- 3	-260	-166	- 86	+ 739	+ 418	+1365	+280	- 11	+ 7	- 87	-167
8	-1644	+ 422	- 544	-404	+157	-255	-257	- 43	+2957	+2176	+3142	+828	+268	+146	+143	- 71
9	- 971	+1172	+ 909	-756	-142	-409	-308	-137	+3076	+1926	+2189	+711	+ 97	+233	+142	- 29
10	+ 832	+2499	+2008	-207	-262	-176	- 80	- 90	+4528	+1760	+2251	+ 29	+ 84	+199	+103	+113
11	+1344	+ 913	+ 418	+ 74	+ 17	- 38	- 21	- 52	-1086	- 628	- 133	+ 13	+ 70	+118	+ 99	+130
12	+1729	+2411	+1495	- 47	- 73	+103	+ 22	+ 31	- 25	- 495	+ 421	- 71	- 45	- 40	+ 29	+ 20
13	+1533	+3115	+2070	+353	+126	+190	+ 41	+ 52	+1523	- 19	+1026	-187	+ 40	-144	+ 5	- 6
14	+2414	+3038	+1731	+274	+254	+124	- 43	+ 66	- 56	- 115	+1192	-536	-516	-229	- 62	-171
15	+1715	+ 818	+ 73	-198	- 25	- 10	- 84	+ 73	+1361	+ 983	+1728	-179	-352	- 56	+ 18	-141
16	+1581	+3457	+ 613	- 22	- 43	+154	+132	+113	+ 699	- 516	+2328	+ 16	+ 37	+ 7	+ 29	+ 48
17	+3092	+4201	+1522	+571	+117	+295	+235	+156	-1981	-2558	+ 121	-280	+174	-137	- 77	+ 2
18	+3085	+2943	+1380	+621	+283	+268	+299	+159	-1140	- 539	+1024	+ 3	+341	- 43	- 74	+ 66
19	+1135	+ 40	- 518	+431	+ 59	+288	+299	+188	-1931	-1083	- 525	-261	+111	- 91	-112	- 1
20	- 296	- 214	- 441	-174	-239	+ 18	+ 52	- 18	-1049	+ 226	+ 453	-378	-313	- 28	- 62	+ 8
21	-1558	- 79	+ 380	-599	-446	- 18	+ 17	+ 27	+1141	+1022	+ 563	+267	+114	+157	+122	+112
22	-1477	- 402	- 99	+ 27	- 88	- 8	+ 80	- 1	+ 675	+ 62	- 241	+ 49	+164	+107	+ 19	+100
23	+ 553	+ 180	+ 296	+243	+ 88	- 22	+ 15	- 6	+ 165	+ 303	+ 187	- 25	+130	+ 72	+ 33	+ 54
24	+ 32	- 414	- 221	-437	+ 8	-130	-154	+ 27	+2560	+2624	+2431	+367	- 78	+111	+135	- 46
25	- 589	- 281	+ 943	-143	+144	-125	-149	+ 5	+1920	+1872	+ 648	+ 43	-244	+ 31	+ 55	- 99
26	+ 478	+ 755	+1245	+ 37	+123	- 78	+ 37	+ 78	+1281	+2835	+2345	+ 71	- 15	- 24	+ 17	- 24
27	+ 227	+ 773	+1152	- 39	-201	- 53	- 56	- 84	+2081	+2512	+2133	-178	- 16	- 51	- 48	- 20

The normal curve derived as above when wrapped around a center and developed clockwise, since the sun's rotation is anticlockwise, is shown on Chart 23. In order to present its most symmetrical appearance it may be referred to two rectangular axes, and the origin should then be changed to the middle of the second day of the ephemeris derived from epoch June 12.22. Accordingly a new ephemeris referred to epoch June 13.72, 1887, has been constructed, of which the January dates for the years 1840–1899 are here given. This investigation was conducted by means of the old ephemeris, but it is thought desirable

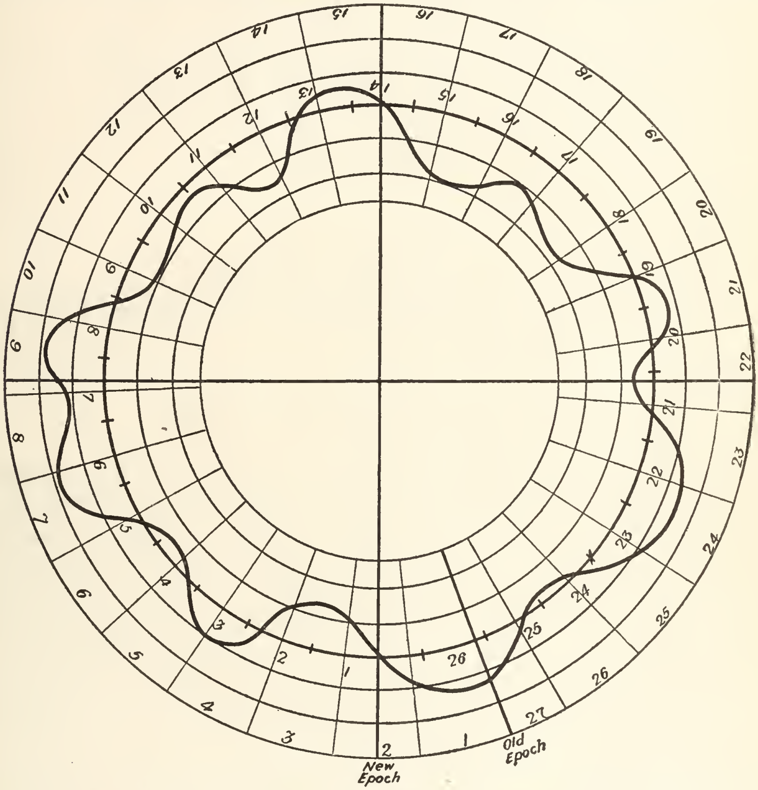


CHART 23.—*Direct type* of the variation of the magnetic and meteorological elements in the 26.68 day period.
Old epoch—June 12.22, 1887.
New epoch—June 13.72, 1887.
Period 26.67928 days.

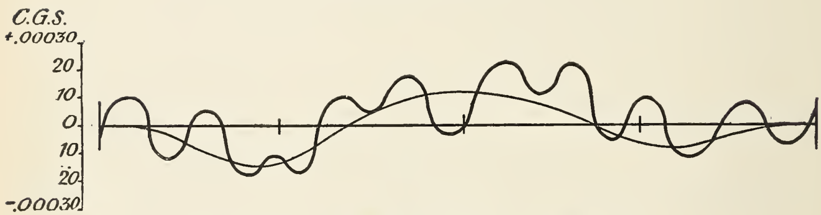
to have the symmetrical type of the curve adopted by others, together with the ephemeris belonging to it. The old curve and ephemeris are found by subtracting 1.50 day from the dates herewith presented in Table 28. The form of the normal periodic curve is also given, and the position of the ends of the rectangular axes are marked along the line of abscissas. For convenience the curve is developed to the right, as the changing aspect of the effect at the earth is thus conveniently presented for study, but it corresponds to an antirotational direction on the sun itself.

TABLE 28.—*Ephemeris of the solar magnetic period.*

[Epoch June 13.72, 1887. Period 26.67928.]

1840.......Jan. 16.87	1860.......Jan. 21.99	1880.......Jan. 27.11
1841.......Jan. 24.38	1861.......Jan. 2.82	1881.......Jan. 7.94
1842.......Jan. 6.21	1862.......Jan. 11.33	1882.......Jan. 16.45
1843.......Jan. 14.72	1863.......Jan. 19.84	1883.......Jan. 24.96
1844.......Jan. 23.23	1864.......Jan. 1.67	1884.......Jan. 6.79
1845.......Jan. 4.06	1865.......Jan. 9.18	1885.......Jan. 14.30
1846.......Jan. 12.57	1866.......Jan. 17.69	1886.......Jan. 22.81
1847.......Jan. 21.08	1867.......Jan. 26.20	1887.......Jan. 4.64
1848.......Jan. 2.91	1868.......Jan. 8.03	1888.......Jan. 13.15
1849.......Jan. 10.42	1869.......Jan. 15.54	1889.......Jan. 20.66
1850.......Jan. 18.93	1870.......Jan. 24.05	1890.......Jan. 2.49
1851.......Jan. 27.44	1871.......Jan. 5.88	1891.......Jan. 11.00
1852.......Jan. 9.27	1872.......Jan. 14.39	1892.......Jan. 19.51
1853.......Jan. 16.78	1873.......Jan. 21.90	1893.......Jan. 27.02
1854.......Jan. 25.29	1874.......Jan. 3.73	1894.......Jan. 8.85
1855.......Jan. 7.12	1875.......Jan. 12.24	1895.......Jan. 17.36
1856.......Jan. 15.63	1876.......Jan. 20.75	1896.......Jan. 25.87
1857.......Jan. 23.14	1877.......Jan. 1.59	1897.......Jan. 6.70
1858.......Jan. 4.97	1878.......Jan. 10.09	1898.......Jan. 15.21
1859.......Jan. 13.48	1879.......Jan. 18.60	1899.......Jan. 23.72

European observations.



Adopted form of the normal periodic curve (direct type).

It may be stated that according to our conception this curve represents the average distribution of a quasi static field surrounding the sun, at the distance of the earth, and therefore it affords the basis for a partial discussion of the state of magnetism within the nucleus of the sun itself, by the spherical harmonic analysis. If the sun maintains this typical field through fifty years without secular change, then the solar nucleus must possess a stability of some sort, quite different from the vaporous condition often assigned by astronomers to the interior of the sun. Agreeing as the 26.68-day period does with the observed rotation of the sun at its visible equator, instead of with the average of the sun-spot rotation, this indicates a circulation of the photosphere like that of the earth's upper atmosphere, at the extremity of a radius of condensation by cooling of the solar material, and thus modifies some other conceptions in solar physics.

Regarding the amplitude adopted for the normal curve, it is simply that which matches the variations of the horizontal component for the latitude of the United States and Europe. Applying it to the total vector *s* in the same latitude, also to the polar regions, enlarging factors are required which can be readily supplied by the data given in other parts of this paper.

SYNCHRONISM OF THE SAME IN THE 11-YEAR PERIOD.

' We now turn our attention to another line of argument to show the synchronous action of the solar and terrestrial elements. It is similar to the data usually given in this connection, such as was collected by van Bebber in Witterungskunde, VI Einfluss der Sonnenflecken auf die Witterung, pp. 199–259. It depends upon the tabulations already described, and some additional compilation on the positions of the storm tracks and the movement of storms. The secular changes can not be attributed to any transient or fortuitous combinations of forces, such as the electromagnetic solar radiation which expends its energy in convectional circulations of short duration, while the atmosphere tends back to a state of equilibrium. On the other hand, they must be referred to some long-sustained state of the medium in which the earth is immersed and which affects its temperature and the other conditions of the circulation of the currents of the air as a whole for great periods of time when compared with the variable states observed in the highs and lows of the weather maps. Such prolonged and sustained changes in the magnetic and meteorological elements can never be explained by transient electric currents of the upper atmosphere, and this constitutes an insuperable difficulty toward regarding that theory of the origin of the observed magnetic forces as sufficient. The first objection raised against the theory was that the actual changes in the magnetic field are too rapid and too widely distributed simultaneously over the earth to be due to local currents of the air in any district; the second objection is now added that other values of the forces are too long sustained to be attributed to such a source. The explanation offered in this paper is that the earth lies in a solar magnetic field, which by its unsteadiness causes all kinds of quick variations in the earth's field, and thus accounts for the first class of changes; and that the same solar field goes through long, steady secular changes as suggested by the sun spots and the other allied phenomena. In both the physics is based upon the fact that an increase in the intensity of the magnetic field lowers the temperature of the atmosphere, and thus influences the convective circulation as a whole, but especially in the polar regions. The simplicity of this view and its cosmical efficiency is such as to readily account for the widely diversified effects that have been ascribed to it. A series of secular results is collected on Tables 29, 30 which will be briefly described.

1. From the Carrington, Spoerer, Greenwich, Washington sun-spot observations, the total spotted area, expressed in units of $\frac{1}{100000}$ part of the disk, for each year, was summed up and the result is put in column 2, Table 30. It develops the curve of sun-spot frequency.

2. If the mean of the numbers along each period in Table 20 of the horizontal component σ, and be taken without regard to sign, the values for 1878 and 1882 appear in the respective columns of Table 29. Similar mean values for other years, 1878–1893, are collected in

TABLE 29.

MEAN VALUES OF THE EUROPEAN HORIZONTAL COMPONENT σ.

[Including disturbances. Sixth decimal C. G. S.]

Mean dates.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.	Means.
Jan. 13.6	63	72	60	128	95	95	89	113	65	68	75	56	49	65	97	124	....	82
Feb. 9.3	56	50	73	121	76	106	98	92	98	65	61	63	52	83	162	129	....	87
Mar. 7.7	61	56	57	79	116	106	83	101	124	62	89	55	55	66	132	91	....	83
Apr. 3.4	56	48	78	74	153	95	98	85	93	73	88	69	44	78	152	94	....	86
Apr. 30.1	71	74	91	76	88	91	100	125	97	64	96	66	49	131	120	91	....	89
May 26.7	73	84	68	91	114	91	82	84	63	62	72	58	45	68	115	93	....	79
June 22.4	69	70	76	95	103	100	122	112	70	66	72	64	48	66	145	97	....	86
July 19.1	59	65	143	78	122	98	81	64	93	75	59	56	52	72	109	130	....	85
Aug. 14.8	50	75	103	69	95	119	102	73	105	77	70	72	50	81	77	80	....	81
Sept. 10.5	58	103	87	109	136	83	135	103	99	72	70	82	66	128	74	100	....	94
Oct. 7.1	59	68	100	86	106	98	98	71	92	84	77	91	63	83	110	132	....	89
Nov. 2.8	83	73	79	106	172	128	108	96	75	70	92	97	46	99	80	86	....	93
Nov. 29.5	75	86	91	86	126	79	115	90	51	76	60	58	46	85	116	99	....	84
Dec. 26.2	61	67	....	73	64	....	93	121	....	85	57	....	40	84	71	....	....	74
Means.....	64	71	85	91	112	99	100	95	88	71	74	68	50	85	111	104	....	85
Variations.	—21	—14	0	+6	+27	+14	+15	+10	+3	—14	—11	—17	—35	0	+26	+19		

MEAN VALUES OF THE NORTHWEST PRESSURES.

[2900+units in table. Unit=0.01 inch mercury.]

Jan. 13.6	101	104	102	108	115	126	125	122	118	105	123	118	113	113	107	125	117	30.14
Feb. 9.3	90	113	103	101	114	129	118	118	110	114	114	125	104	103	115	111	120	30.12
Mar. 7.7	88	117	95	94	110	98	111	120	109	111	107	103	108	104	105	94	106	30.04
Apr. 3.4	71	93	78	102	98	101	96	100	94	100	105	96	104	97	104	100	98	29.99
Apr. 30.1	92	93	83	98	92	91	96	89	97	91	98	93	102	104	103	89	90	29.94
May 26.7	91	89	87	89	85	89	92	84	88	91	84	98	93	90	90	84	92	29.89
June 22.4	92	88	95	90	91	92	88	89	88	91	82	94	88	93	96	89	91	29.90
July 19.1	90	95	101	98	97	99	88	87	89	98	105	96	93	98	93	89	93	29.95
Aug. 14.8	94	91	99	96	100	106	89	95	95	97	106	95	101	105	102	91	96	29.98
Sept. 10.5	95	91	103	96	98	108	90	97	98	100	110	105	101	96	95	100	94	29.99
Oct. 7.1	95	107	108	121	101	110	107	107	109	104	108	117	98	109	112	109	96	30.07
Nov. 2.8	100	96	114	114	123	112	122	109	113	115	114	110	115	111	108	109	114	30.12
Nov. 29.5	113	102	102	124	120	132	121	126	113	112	108	100	120	103	121	114	104	30.14
Dec. 26.2	118	88	....	119	124	....	115	122	....	114	117	....	112	115	117	....	127	30.16
Means.....	95	98	98	104	105	107	104	106	102	103	106	104	104	103	105	100	103	30.03
Variations.	—8	—5	—5	+1	+2	+4	+1	+2	—1	0	+3	+1	+1	0	+2	—3	0	

TABLE 29—Continued.

MEAN VALUES OF THE NORTHWEST TEMPERATURES.

[Units in degrees Fahrenheit.]

Mean dates.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.	Means.
Jan. 13.6	25	20	15	—3	11	1	6	—2	6	—5	0	8	—4	14	11	—1	8	6
Feb. 9.3	32	19	18	8	18	19	—1	7	19	—6	6	13	9	3	22	14	12	13
Mar. 7.7	41	31	38	22	25	25	13	25	30	23	7	36	12	17	24	32	27	26
Apr. 3.4	45	51	49	30	40	41	36	42	50	36	41	50	38	45	39	44	41	42
Apr. 30.1	50	58	60	53	51	52	50	52	60	52	45	53	47	52	50	58	57	53
May 26.7	61	64	65	65	61	63	61	61	65	62	62	65	56	59	63	71	67	63
June 22.4	72	72	70	67	64	65	68	65	74	70	66	69	70	64	69	72	72	69
July 19.1	75	67	68	70	66	64	64	68	66	69	65	68	71	66	72	69	75	68
Aug. 14.8	71	65	60	68	67	60	65	56	59	63	64	62	63	64	59	62	71	64
Sept. 10.5	58	60	49	52	51	45	56	56	52	57	51	52	56	60	59	45	55	54
Oct. 7.1	46	46	36	40	41	35	49	41	40	44	40	38	50	46	41	39	45	42
Nov. 2.8	40	32	11	28	25	21	32	30	14	36	26	23	35	24	22	15	30	27
Nov. 29.5	23	6	18	25	11	1	21	18	2	11	22	15	27	22	8	11	26	16
Dec. 26.2	5	23	....	20	—6	....	—3	1	....	—4	13	....	24	0	9	....	8	8
Means	46	44	43	39	37	38	37	37	41	36	37	42	40	38	39	41	42	40
Variations.	+6	+4	+3	—1	—3	—2	—3	—3	+1	—4	—3	+2	0	—2	—1	+1	+2	....

MEAN AMPLITUDES OF THE NORTHWEST PRESSURES.

[Units in hundredths inches.]

Mean dates.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.	Means.
Jan. 13.6	13	23	24	18	16	19	14	14	11	27	18	12	21	14	14	18	20	17.4
Feb. 9.3	18	27	30	17	17	17	12	10	13	17	17	13	19	19	12	20	25	17.8
Mar. 7.7	21	15	23	11	19	13	10	9	12	16	16	19	24	15	22	17	25	16.9
Apr. 3.4	19	16	16	12	17	16	17	12	14	13	15	19	16	17	12	10	12	14.9
Apr. 30.1	17	16	13	12	14	16	12	14	10	17	14	18	14	12	14	16	15	14.4
May 26.7	9	15	11	9	11	9	12	10	7	11	13	13	13	15	13	10	10	11.2
June 22.4	7	10	12	7	9	12	7	9	6	10	15	9	9	11	10	10	12	9.7
July 19.1	8	8	10	8	9	9	7	6	9	8	9	9	10	9	10	8	8	8.5
Aug. 14.8	9	16	14	7	10	13	10	7	11	9	7	14	9	11	10	14	8	10.5
Sept. 10.5	17	20	14	12	12	13	10	15	16	13	12	18	10	13	13	19	16	13.7
Oct. 7.1	22	22	17	11	18	24	16	11	20	17	11	15	12	15	13	17	15	16.2
Nov. 2.8	18	22	21	19	12	20	11	13	23	14	15	19	13	18	16	19	16	17.0
Nov. 29.5	19	18	18	13	21	24	10	12	15	17	16	13	17	21	10	15	19	16.4
Dec. 26.2	19	19	....	13	14	....	16	15	....	21	15	....	15	26	15	....	20	17.3
Means	15.4	17.6	17.2	12.1	14.2	15.8	11.7	11.2	12.8	15.0	13.8	14.7	14.4	15.5	13.1	14.8	15.8	14.4
Variations.	+1.0	+3.2	+2.8	—2.3	—0.2	+1.4	—2.7	—3.2	+1.6	+0.6	—0.6	+0.3	0.0	+1.1	—1.3	+0.4	+1.4	....

TABLE 30.—*Comparison of the secular variations of the sun spots, the European magnetic field, and the American meteorological system.*

Elements.	Spotted areas of sun.	European magnetic component σ.	American N. W. temperature (25).	N. W. temperature (10 stations).	N. W. pressure (10 stations).	Storm movements in longitude.		Storm movements in latitude.			Cold wave.	Temperature amplitudes.	American meteorological system.
						Lows.	Highs.	N. Lows.	S. Lows.	S. Highs.			
1878	93	64	50.7	46	29.95	......	......	......	......	......	......	......	—2.7
1879	153	71	48.9	44	29.98	......	......	......	......	......	......	6.7	—1.5
1880	1592	85	47.8	43	29.98	......	......	......	......	......	......	6.4	—0.9
1881	2699	91	47.5	39	30.04	......	......	......	......	......	......	6.3	+0.7
1882	3674	112	46.2	37	30.05	1.99	1.76	5.33	1.75	2.21	4.06	6.2	+1.7
1883	4370	99	45.0	38	30.07	2.49	1.84	5.67	1.81	2.05	3.79	5.9	+1.5
1884	3815	100	45.8	37	30.04	2.44	2.00	5.55	1.63	2.02	3.67	6.5	+0.4
1885	3364	95	45.8	37	30.06	2.15	2.08	5.47	1.82	1.99	3.99	6.9	+1.1
1886	1433	88	46.6	41	30.02	2.24	1.83	5.35	1.72	2.11	3.90	6.6	+0.7
1887	725	71	46.5	36	30.03	2.44	2.06	5.15	1.76	2.03	3.86	7.1	0.0
1888	410	74	45.9	37	30.06	2.17	2.19	5.35	1.68	2.04	3.87	6.4	+1.1
1889	287	68	48.1	42	30.04	2.19	1.94	5.37	1.71	1.96	3.57	6.2	—0.1
1890	402	50	47.8	40	30.04	2.37	2.22	5.25	1.65	1.89	3.78	6.7	—0.5
1891	2119	85	47.0	38	30.03	2.14	2.16	5.25	1.61	1.94	3.92	6.6	+0.3
1892	5100	111	46.5	39	30.05	2.38	1.91	5.19	1.78	1.94	3.96	6.2	+0.7
1893	4500	104	46.0	41	30.00	2.50	2.16	5.05	1.60	2.06	3.71	7.1	—0.9
Units.	$\frac{1}{100000}$ of the surface.	6th decimal. (C. G. S.)	Fahrenheit (degrees).	Fahrenheit (degrees).	Inches of mercury.	300 miles.	300 miles	200 miles.	200 miles.	200 miles.	200 miles.	Fahrenheit (degrees).	Arbitrary.
Related.	Direct.	Direct.	Inverted.	Inverted.	Direct.	Inverted.	Inverted.	Direct.	Direct.	Direct.	Direct.	Inverted.	Direct.

the same table. These numbers measure the relative strength of the impressed field superposed upon the earth's normal field; also the mean annual variation, which is the average range in amplitude, and expresses the tendency to depart from a uniform normal field. On Table 29, under mean dates, is given the mean of the dates on which the successive periods began for the years considered. The mean of the tabular values for the columns and rows gives the tendency in this force to vary throughout the year, and also from year to year. It shows a positive synchronism with the spotted area in the secular period; but in the annual period merely irregularities which may possibly contain symptoms of the inversion phenomenon. It will be necessary for students holding the view of atmospheric electric currents as the cause of these phenomena to show how it is that the secular variation is pronounced and synchronous with the sun-spot period, while the annual shows no tendency to exhibit a variation with the sun's declination, upon which the entire system of meteorological convective currents primarily depends and to which the currents themselves are referred. Diagrams of the secular curves are found on Chart 24, and may be consulted in passing.

3. An exactly parallel discussion of the pressure and the temperature data of Tables 22, 23, and of the other years of the series 1878–1894 is

collected on Table 29, the secular and annual means being taken. These are transferred to Table 30, and plotted on Chart 24. Likewise the mean annual temperature of 80 stations in the United States, also of 25 northwest stations, has been computed, the results being similar to those before presented. To conform with the sun-spot curve, the temperature curve is inverted, and the pressure is direct. This means that an increase of solar magnetic intensity is synchronous with a diminution of temperature, but with an increase of pressure, and this function persists throughout every phase of the research. In spite of some irregularity, there is a distinct conformity in the general sweep of these

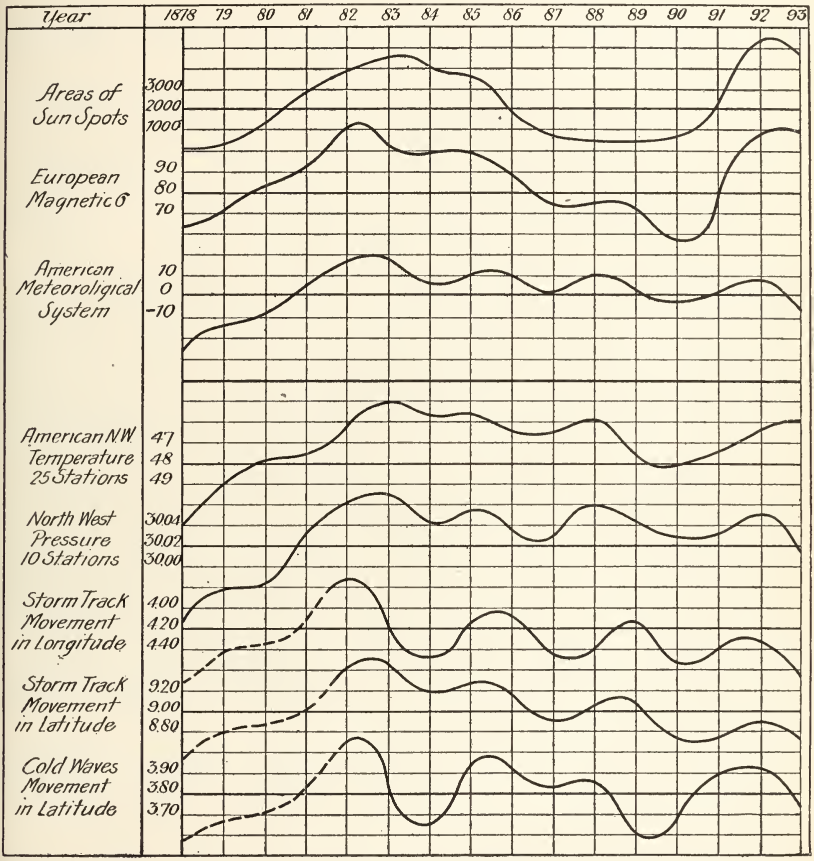


CHART 24.—Diagram of the relative secular variations in the sun spots, the European magnetic field, and the American meteorological system.

curves, and also in the tendency to describe crests during the same years. Indeed, the occurence of four subordinate crests in the 11-year periods suggests strongly that a $2\frac{3}{4}$-year period is superposed upon the long sweep of that periodic curve. Apparently this is more at the basis of the seasonal variations of the weather conditions of the United States than anything else, so that in long-range forecasting this period

must be very carefully considered. Unfortunately the great labor of computing the component σ for many years, and the fact that the northwest temperature observations are not complete previous to the year 1878, makes it difficult to trace the variations backward. The lapse of time will, however, enable us in the future to confirm this periodicity, if it persists.

RELATIVE EFFICIENCY OF THE SEVERAL FORCES.

In order to estimate the approximate efficiency of the external magnetic field in affecting the meteorological elements, it is seen, Table 29, that the annual range of temperature was about 60° F., while in the secular period it was about 7° or 8°—that is, one-eighth as large. The magnetic field has probably about one-eighth of the power of the common insolation to change the temperatures of the Dakota region. The action, of course, is very complicated, being propagated through the convectional system, whereby highs and lows traverse that district, but yet its efficiency represents an important though indirect part of the temperature force operating in the interior of the North American continent. In the same way the mean annual range in pressure is about 0.24 of an inch of mercury, while in the secular period it is about 0.08 of an inch—that is, one-third the annual change. I have therefore felt justified in believing that about 25 or 30 per cent of the weather conditions of the Dakota region are very closely connected with the magnetic sources. It may be stated that the application of the ephemeris and periodic curve to the northwest would forecast about 75 per cent of the crests, provided the exact time of inversion of the curve were known in advance. It is this complication which has prevented the scheme having an immediate value for practical work. At present the conditions are not sufficiently well understood to venture on the public forecasts, and I suppose that the required final knowledge of the physical conditions will only come as the result of a long campaign, which implies the establishment of permanent observatories on Northern Rocky Mountain Slope. The total lack of magnetic observations there is a great obstacle to the suitable completion of this research and to securing a practical result.

The annual range in the pressure amplitudes—that is, the extreme tendencies to strong or weak highs and lows, respectively, which are characteristic of the winter and the summer season—is about 0.08 of an inch, while the secular range is about 00.4 of an inch—that is, 50 per cent. One of the most marked features of the study of the curves of magnetic and meteorological elements from year to year is the fact that in some years the curves are turbulent and in others quiet. The gradual change from one extreme to the other, which has occurred several times in the magnetic curves since 1841, leaves the impression that the solar action is persistent, but going through secular variations. To reverse this view, as the theory of upper air electric currents

requires, is unsound, since it implies that the earth's magnetic field influences the sun itself. Unless it can be shown by observations that the electromagnetic field has a secular variation in intensity, these slow changes can not be referred to that radiation as their cause. This has never been done, the results of observation being negative. On the other hand, the observational proof of the variation of the direct magnetic field is clear and of a kind to accord with the nature of the observed effects. The annual range in temperature amplitudes is about 6° F., and the secular range about 1°. The data appears on the twelfth column of Table 30.

An extensive computation of the location of the mean tracks of the highs and lows of the United States, whose results are mentioned in Bulletin No. 20 of the Weather Bureau, has been executed, to the following effect. The mean position of the highs and lows as they drift eastward go through a series of accelerations and retardations; also the mean tracks change their location, as a whole, in latitude. This computation includes the cold-wave tracks. The result is placed in columns 6–11 of Table 30. The value of the units in inches is indicated, and the fact that the longitude curves are inverted, while the latitude curves are direct. This means that in years of increased magnetic impulse the tracks lie farther north and the eastward movements are slower by the amount indicated, the extremes being about 150 miles east and west and 40 miles north and south for the highs and lows; the cold-wave tracks are more to the north in the stronger magnetic years. The curves conform to the type set by the magnetic curve and should individually be compared with it. If it be assumed that each of the individual curves here brought forward from the American meteorological system, is a more or less accurate measure of the action of that force which causes the changes synchronously in all the elements, then the mean of the ordinates of these meteorological curves will furnish the average type, which is given in the last column of Table 30, and the third curve of Chart 24. A comparison of this mean American meteorological curve with the European magnetic curve, certainly shows conformity to such an extent as to exclude merely accidental physical relations. Should such a result be obtained also in the future, it will be a demonstration of the synchronism of the two systems of forces under consideration.

TABLE 31.—*The solar magnetic force, West Indies hurricane frequency, movement in longitude, and number of highs and lows in the 26.68-day period.*

Days of the 26.68-day period.																										
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Normal variations of the solar magnetic force.																										
—6	—4	+12	—8	—5	+5	—16	—11	—17	0	+12	+5	+19	+5	—4	+5	+23	+13	+20	+17	—6	+8	+4	—13	—5	+4	—10
West Indies hurricane frequence for the years 1874–1893.																										
3	6	5	4	4	5	7	3	5	10	5	5	6	5	1	11	9	6	5	5	5	6	2	4	7	7	3
Relative mean daily movement in longitude of U. S. highs and lows.																										
+2.0	+1.1	+0.7	—1.0	—0.5	+1.8	+1.9	+0.5	—2.3	—0.6	—0.3	—1.0	+1.9	—2.1	—0.3	+0.3	—0.4	+0.7	+0.3	—0.2	—0.8	—0.2	—0.8	—0.8	—1.7	—1.4	......
Relative numbers of highs and lows in the Northern Hemisphere, 1883 and 1887.																										
14	10	31	18	11	27	17	21	23	15	31	36	39	42	33	38	41	45	34	34	33	32	23	25	32	27	29

SOME MISCELLANEOUS DATA SHOWING SYNCHRONISM IN THE 26.68-DAY PERIOD.

It is, perhaps, unnecessary to adduce more evidence of the interdependence of these forces; but it may be stated that one can hardly attack any of the meteorological problems by means of the 26.68-day period, provided that the eastward drift be allowed for with the accompanying convectional changes, without reproducing the normal curve with some degree of precision. Usually it requires many observations to do so; but this is, of course, due to the necessity of separating indirectly the two closely interwoven systems. In the magnetic field, the auroras, and the earth's currents the time correction is not needed. In the extreme northwest the time is the same; but everywhere else

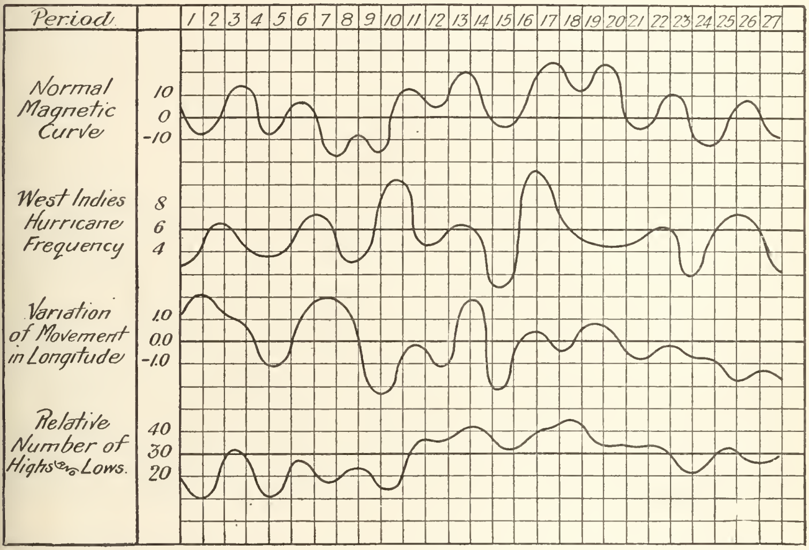


CHART 25.—Diagram of the magnetic force, hurricane frequency, movement in longitude, and number of highs and lows in the 26.68-day period.

the ephemeris must be adjusted for longitude to the place of operation. As further examples we may incite the following curves of Chart 25 from the values collected on Table 31.

No. 1 is the typical solar magnetic curve already found. No. 2 is the relative frequency of the occurrence of the West Indies hurricanes for the years 1874–1893, as given in Table 31, and it shows a tendency to form such storms along with the increase of the magnetic impressed force. No. 4 is the curve of the relative frequency in the number of high and low centers counted on the International Charts for 1883 and 1887. It displays the same general impulse. Apparently the entire hemisphere at certain dates breaks out into more rapid circulation, whereby the large highs disintegrate into smaller parts, and the number of cyclonic centers is at the same time increased. From the

tabulations of the positions of the storms tracks of the United States when collected in the 26.68-day period, the summary in curve No. 3 shows a tendency to produce the same fundamental curve as the magnetic impulse.

It is seen from the foregoing exposition of the data that the synchronism between the magnetic field and the meteorological elements persists from day to day, in short and in long periods, and under a great variety of geographical conditions. Reasons have been given for accepting the view of the direct solar magnetic action, based upon the direction of the impressed vectors, their periodicity in a rotation time agreeing with that of the sun at its equator, and also in the 11-year period of the sun-spot frequency. It was shown that the arguments usually accepted as decisive against direct action are partly misconceived by reason of the mistaken identification of the observed diurnal variations with the direct polar field of the sun, while our exposition shows that these belong to the electro-magnetic field, and not to the direct field at all. Compare the argument of Chambers reviewed in Chapter 1, page 17. The extreme difficulty of assigning to hypothetical electric currents of the upper atmosphere such sources and activities as will account for the operation of the magnetic variations over the entire earth simultaneously in short and long impulses, as well as the impossibility of transmitting the observed changes on the earth to the sun in order to explain the observed operations there, influences us to advocate the direct magnetic action of the sun as the cause, while the atmospheric currents of electricity and the convectional currents are synchronously dependent upon it. There is no disposition to minimize the efficiency of the tropical insolation in its effects upon the atmosphere, but merely to supplement it with such forces as are called for by known facts, in order to explain fully the entire range of the phenomena of terrestrial magnetism and meteorology.

Chapter 6.

SOLAR MAGNETISM.

THE SOLAR CORONAS OF JULY 29, 1878, JANUARY 1, 1889, DECEMBER 22, 1889.

Having reviewed the material at our disposal analyzed to show the variations of the terrestrial magnetic field and the synchronous changes among the meteorological elements of the atmosphere, it is fitting to collect such evidence as we possess of the magnetic state of the sun itself. The strongest line of argument is of course the one traversed, namely, that there is an impressed external field of force within the earth's field whose representative curve is periodic, the period agreeing very closely with the well-known visible rotation of the sun's photosphere at its equator. The explanation of the inversion of type of the impressed field, to be taken up in the course of this chapter, constitutes the most uncompromising evidence in favor of the view that the direct action of the sun's magnetic force is at the basis of the observed variations of the earth's magnetic field, other than the diurnal variations and the annual changes peculiar to these.

It is proper to recall that this investigation had its beginnings in a study of the rays of the solar corona, visible during eclipses, and that the proposition then was to explain their apparent curvature by the equation representing the lines of force of the magnetic field surrounding a spherical magnet. The leading results will be mentioned here, but without the details contained in the original papers.* On charts 26, 27, 28 are seen the diagrams of the coronas of the eclipses July 29, 1878, January 1, 1889, December 22, 1889, plotted as dotted lines. These eclipses occurred near the minimum of the sun spot disturbances, Chart 30, and such occasions seem to be the only ones when the sun is sufficiently quiet to exhibit the normal, undisturbed state of its typical system. Other eclipses give very confused pictures of coronal lines, and are unsuited for studying the problem in hand. The lines appearing on a photograph of the corona are of course rifts in the material surrounding the sun, seen projected on a plane perpendicular to the line of sight. A magnetic solar field may have the power to arrange this material approximately along the lines of force, just as is the case with the iron fillings used in tracing out a field around a steel magnet.

*Compare Amer. Journ. Sci., Nov., 1890; July, 1891. Astron. Soc. Pac., No. 14, 1891; No. 16, 1891. The Solar Corona. Smithsonian Institution, 1889.

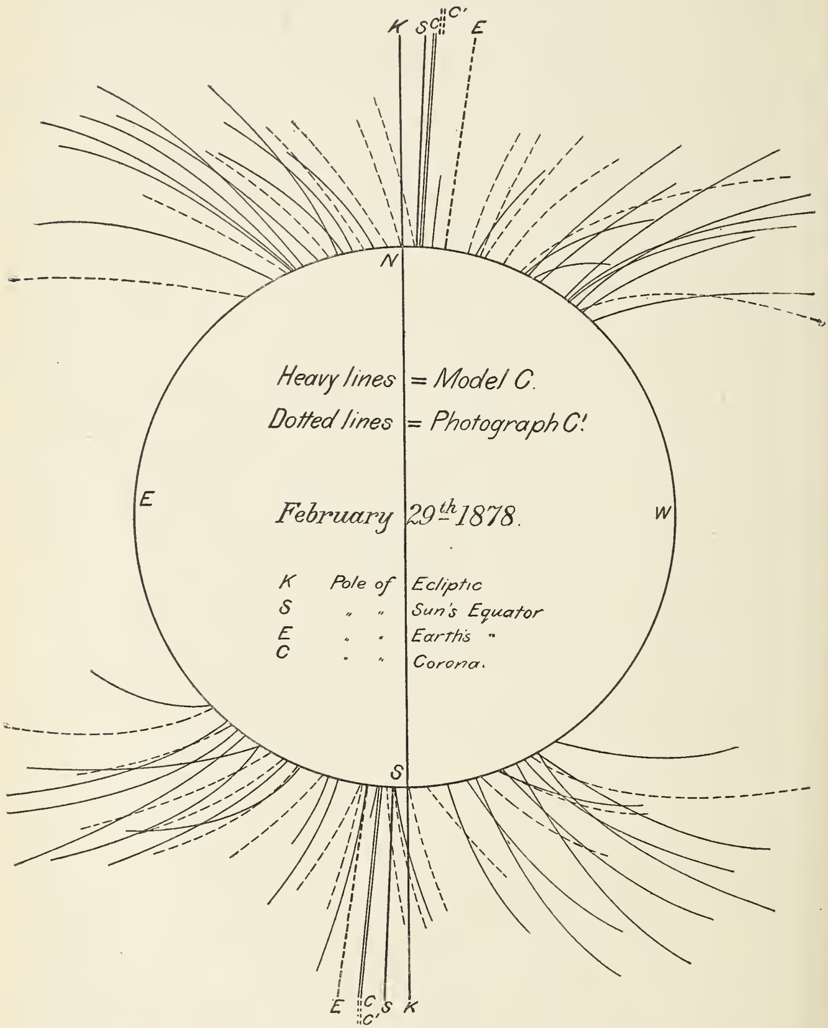


CHART 26.—Comparison of the model with the coronal lines for the eclipse, July 29, 1878.

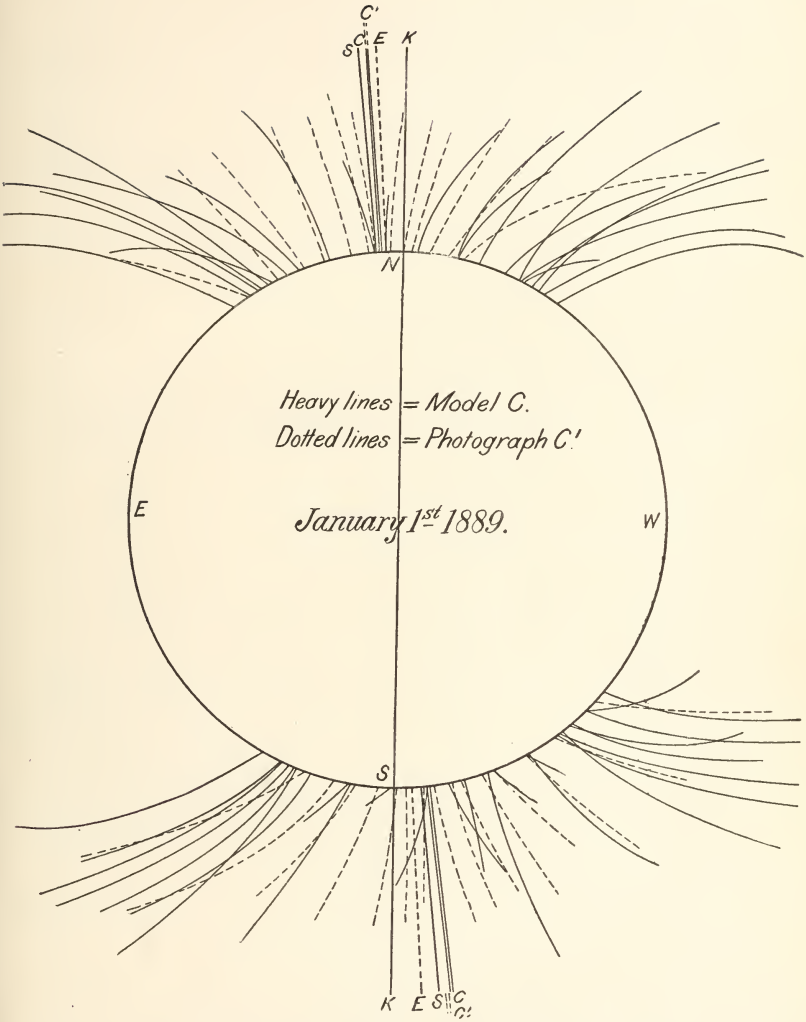


CHART 27.—Comparison of the model with the coronal lines for the eclipse, January 1, 1889.

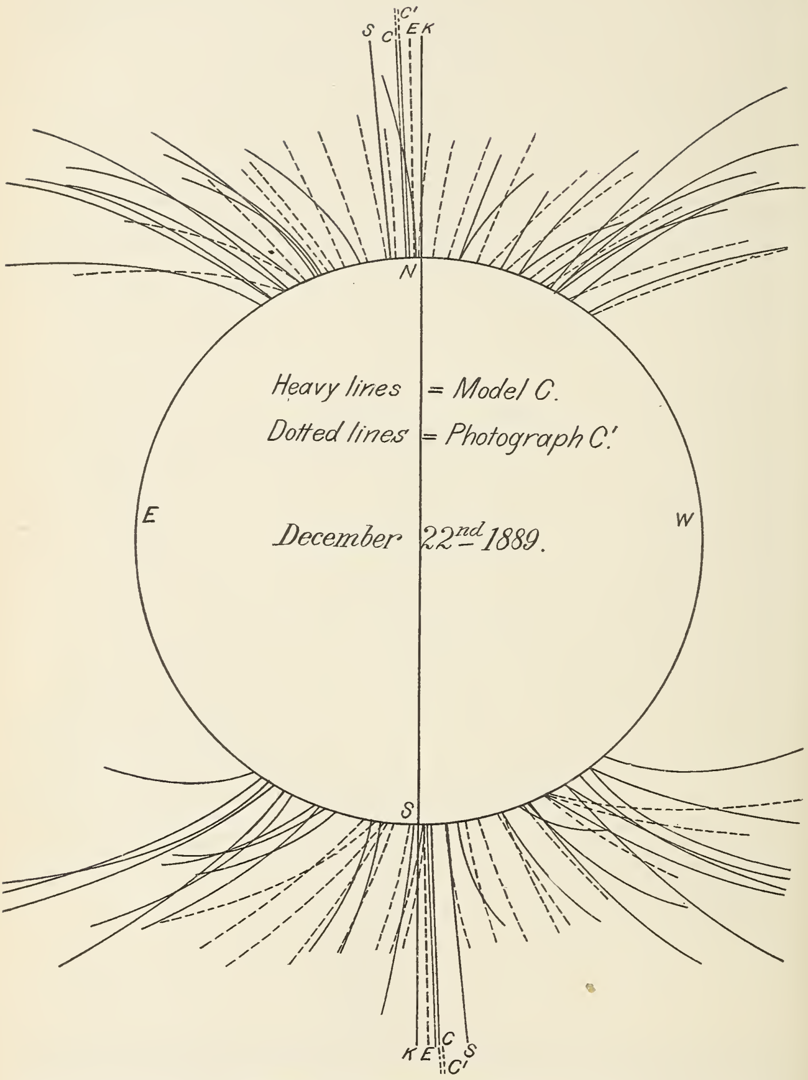


CHART 28.—Comparison of the model with the coronal lines for the eclipse, December 22, 1889.

Hence, these visible lines can be employed in discussing the geometrical system thus mapped out. The dotted lines on the charts simply reproduce the available rifts traced on the negatives, and in this respect they merely stand for the original photographs taken during the eclipse.

Equation of the lines of force, $N = \frac{8\pi}{3} \frac{\sin^2\theta}{r}$.

The measured line is that projected from its true position in space upon the plane through the center of the sun, perpendicular to the line of sight. From the coordinates $(r.\ \theta.)$ of points on the photograph of an individual ray we compute the corresponding values on the ray itself before projected from the original plane, which makes the angle α with the plane of projection.

$$x = r \sin\theta.$$
$$y = r \cos\theta.$$
$$r = \sqrt{x^2+y^2}.$$
$$\sin^2\theta = \frac{x^2}{r^2} = \frac{x^2}{x^2+y^2}.$$

As a first approximation, suppose the axis of the sun to be perpendicular to the plane of the ecliptic, so that the projected point would move across the disk during rotation in a line parallel to the ecliptic.

$$X\ Y = \text{true position.}$$
$$r \sin\theta = \text{radius of revolution.}$$
$$x = X \cos\alpha = r \sin\theta \cos\alpha.$$
$$y = Y.$$
$$N = \frac{8\pi}{3} \cdot \frac{x^2}{(x^2+y^2)^{3/2}} = \frac{8\pi}{3} \cdot \frac{r^2 \sin^2\theta}{(r^2 \sin^2\theta \sec^2\alpha + r^2 \cos^2\theta)^{3/2}}.$$

Since the coordinates $(r_1\ \theta_1)$, $(r_2\ \theta_2)$, $(r_3\ \theta_3)$ are assumed to belong to the same line of force, we have,

$$\frac{r_1^2 \sin^2\theta_1}{(r_1^2 \sin^2\theta_1 \sec^2\alpha + r_1^2 \cos^2\theta_1)^{3/2}} = \frac{r_2 \sin^2\theta_2}{(r_2^2 \sin^2\theta_2 \sec^2\alpha + r_2^2 \cos^2\theta_1)^{3/2}}.$$

Take for abbreviation, $X_1 = r_1 \sin\theta_1$; $X_2 = r_2 \sin\theta_2$
$Y_1 = r_1 \cos\theta_1$; $Y_2 = r_2 \cos\theta_2$,

and we obtain,
$$\sec^2\alpha = \frac{X_2^{4/3}\, Y_1^2 - Y_2^2\, X_1^{4/3}}{X_1^{4/3}\, X_2^2 - X_2^{4/3}\, X_1^2}.$$

TABLE 32.—*Computed polar distance of the base of the visible rays of three coronas.*

Corona of July 29, 1878. [Quadrants of rays.]							
NE.		NW.		SW.		SE.	
	° ′		° ′		° ′		° ′
1	30. 40	1	33. 5	1	35. 0	1	31. 41
	28. 35		30. 17		31. 41		33. 25
2	28. 32		30. 2		30. 21		29. 28
3	28. 43	2	28. 2	2	29. 22	2	30. 28
	32. 55		27. 41		31. 23		32. 34
	30. 59		26. 11		30. 44	3	34. 25
4	31. 8	3	36. 30	3	33. 59		34. 59
	33. 39		34. 5		32. 26		31. 48
	30. 32		32. 5		30. 50	4	33. 45
5	32. 41	4	34. 52	4	30. 17		34. 1
	33. 17		33. 30		31. 25		31. 38
	31. 32		32. 26		30. 14	5	34. 1
6	33. 25	5	34. 24	5	33. 51		34. 19
	33. 18		35. 0		35. 51		33. 25
	34. 34		34. 23		33. 20	6	34. 52
7	36. 0		33. 5	6	36. 33		34. 54
	36. 23		31. 29		36. 35		32. 38
	35. 16	6	41. 55		35. 41	7	35. 8
8	42. 25		41. 58	7	38. 59		35. 13
	42. 23		40. 49		38. 57		35. 11
	40. 16			8	41. 6	8	39. 7
					41. 7		39. 11
					40. 30		38. 39
							37. 26
	33. 41		33. 36		34. 21		34. 16
			33°. 59′				

Corona of January 1, 1889. [Quadrants of rays.]							
NE.		NW.		SW.		SE.	
	° ′		° ′		° ′		° ′
1	37. 36	1	30. 22	1	32. 8	1	31. 44
	33. 46		31. 28		32. 39		32. 40
	33. 20		29. 49		30. 42		31. 11
2	27. 19	2	30. 1	2	31. 1	2	27. 47
	29. 44		30. 34		29. 0		27. 4
	28. 18		27. 59		29. 27		27. 17
3	24. 45	3	32. 7	3	31. 29	3	29. 56
	24. 28		33. 1		32. 16		30. 14
	24. 45		31. 7		30. 53		29. 51
4	18. 38	4	32. 7	4	30. 27	4	32. 24
	17. 51		33. 48		30. 41		33. 8
	17. 35		31. 0		29. 25		31. 17
5	31. 17	5	33. 7	5	34. 27	5	33. 23
	30. 53		34. 31		35. 10		33. 55
	31. 29		31. 57		33. 26		32. 46
6	38. 0	6	34. 14	6	29. 25	6	33. 24
	38. 25		34. 36		29. 29		34. 50
	37. 3		33. 33		29. 5		33. 10
7	43. 11		31. 17	7	37. 49	7	34. 53
	43. 5		30. 4		35. 53		35. 31
	42. 17				36. 28		32. 55
				8	42. 55	8	37. 49
					43. 11		37. 17
					42. 2		35. 30
	31. 8		31. 50		33. 19		32. 35
			32°. 13′				

Corona of December 22, 1889. [Quadrants of rays.]							
NE.		NW.		SW.		SE.	
	° ′		° ′		° ′		° ′
1	33. 16	1	28. 33	1	30. 50	1	31. 35
	30. 22		29. 27		32. 21		31. 30
	27. 35		28. 33		30. 33		31. 26
2	25. 31	2	25. 7	2	28. 9	2	32. 4
	25. 42		24. 58		27. 12		33. 39
	25. 27		25. 28		26. 37		30. 4
3	30. 33	3	29. 0	3	28. 14	3	31. 46
	31. 9		29. 0		28. 11		31. 53
	29. 57		28. 59		28. 18		31. 24
4	27. 25	4	26. 0	4	26. 56	4	31. 16
	27. 32		25. 59		27. 15		31. 19
	26. 41		26. 4		26. 46		31. 6
5	30. 15	5	34. 1	5	28. 58	5	32. 35
	30. 12		34. 22		29. 2		32. 48
	30. 17		33. 24		29. 31		31. 19
6	31. 38	6	34. 13	6	34. 33	6	33. 4
	31. 42		34. 32		34. 50		33. 31
	31. 9		33. 40		33. 52		32. 12
7	31. 28	7	34. 23	7	36. 40		30. 33
	31. 39		34. 31		36. 38	7	33. 56
	31. 1		34. 1		36. 34		33. 41
8	28. 43	8	38. 22	8	37. 34		32. 29
	28. 37		38. 43		37. 55		
	28. 48		37. 37		37. 25		
9	35. 59	9	39. 39		36. 5		
	36. 0		39. 40				
	35. 47		38. 33				
10	38. 7						
	38. 24						
	37. 31						
	30. 57		32. 6		31. 38		32. 3
			31°. 41′				

If θ_0 is the angular distance from the coronal pole at which the ray reaches the surface of the sun, in the plane making the angle α with the plane of the disk,

$$\mathrm{Sin}^2\,\theta_0 = \frac{x^2 \sec^2\alpha}{(x^2 \sec^2\alpha + y^2)^{3/2}}$$

The detailed results of the computation may be found in the publications of the *Astronomical Society* of the *Pacific* (Vol. III, No. 16, 1891). The value of θ_0 for each measured ray, in the several quadrants of the three coronas specified, are reproduced in Table 32. An inspection of these angles, from the base of the rays to the poles of the sun—more properly to the pole of the magnetic system—shows that there is a remarkably persistent law, according to which these rays spring from the sun in a narrow belt 10° or 15° wide, whose central circle is 32° 38′ polar distance for these coronas. The corona bases of 1889 are on the average about 2° nearer the poles than those of 1878. It may be observed that these results do not favor the view that the base of the visible coronal rays lies within the sun-spot belt. Hence any theory depending upon that supposition must draw upon other observational data than that immediately under consideration for its support. If the confused mass of rays, usually seen along the equatorial regions of the sun, proceeds from lower latitudes than the coronal belt, as they should according to this scheme of magnetic lines of force, then their individuality is lost in the superposition caused by the optical projection. The massing of the coronal lines in the well-known four quadrantal protuberances is naturally explained by the geometrical distribution here advocated; the open array of the rays in the polar regions is also likewise accounted for conformably with it. Why the rays should develop separately along the belt indicated is not understood. The analogy with the terrestrial auroral lines is very plausible, but probably misleading, since, according to the exposition in an earlier chapter, those were due to the action of a permeable shell placed in an external field of magnetic force; but we can connect the sun with no such independent exterior field.

Continuing the detailed computation referred to in the paper of the A. S. P., it was found that the poles of the corona appeared to be 4.5° from the sun's poles; also separated by about 100° in longitude, the south pole preceding. The computation in the same paper regarding the period of rotation proves to be incorrect, because the wrong number of revolutions was assumed between January 1 and December 22, 1889. It should have been 13 instead of 12. This subject may be taken up again some time, especially if another satisfactory photograph of the corona, showing separate coronal lines, can be secured.

A model of the coronal streamers was now constructed from this data, by inserting wires on a ball 5 inches in diameter along two belts, one in either hemisphere, at the mean polar distance of 33°, measured from two points taken as the poles of magnetization. These are located 5°

from the axis of rotation of the ball, the lower 100° in advance of the upper. The wires have the curvature conforming to the lines of force at the given polar distance as developed from the ordinary formula. The ball was then mounted on a stand whose base represents the plane of the ecliptic, having an axis inclined at 7° to that plane. If this is in reality a counterpart of the sun's coronal structure, then it is only necessary to locate the ball in agreement with the relative positions of the sun and the earth at the eclipse, assuming that the south coronal pole is on the central meridian of the sun at the beginning of the periods of the 26.68 day ephemeris. These positions of the sun and earth can be found on the accompanying Table 33 for seven eclipse dates. At any date corresponding to the day of the ephemeris beginning a new period, as given in the third line of the table, the south coronal pole should be central on the sun toward the earth; at any other date proportionately advanced. The direction of the earth from the sun, relative to the axis of rotation, at any date is well known from the spherical triangle K. S. E. Hence the model can be set according to this provisional data for any desired epoch.

TABLE 33.—*Computation of the longitudes of the coronal poles at seven eclipses between 1878 and 1893.*

Year.	1878.	1882.	1883.
	d h m	d h m	d h m
Date of eclipse, G. M. T	July 29 9 23	May 16 19 42	May 6 9 45
Do	July 29.39	May 16.82	May 6.41
Next preceding epoch	July 14.26	May 1.32	Apr. 13.46
Elapsed interval, days	15.13	15.50	23.95
	°	°	°
Elapsed interval, degrees	219.1	224.4	346.8
Longitude of sun	112.2	41.3	23.8
Reduction to heliocentric longitude	180.0	180.0	180.0
Approximate heliocentric longitude of S. coronal pole	161.3	85.7	190.6
Approximate heliocentric longitude of N. coronal pole	55.3	339.7	84.6
Heliocentric longitude of the earth at the eclipse	306.6	236.3	226.0

Year.	1886.	1889.	1889.	1893.
	d h m	d h m	d h m	d h m
Date of eclipse, G. M. T	Aug. 29 0 59	Jan. 1 9 16	Dec. 22 0 53	Apr. 16 2 27
Do	Aug. 29.04	Jan. 1.39	Dec. 22.04	Apr. 16.10
Next preceding epoch	Aug. 22.74	Dec. 23.50	Dec. 5.34	Apr. 15.60
Elapsed interval, days	6.30	8.89	16.70	0.50
	°	°	°	°
Elapsed interval, degrees	92.5	128.7	241.8	7.2
Longitude of sun	150.0	272.7	254.1	26.8
Reduction to heliocentric longitude	180.0	180.0	180.0	180.0
Approximate heliocentric longitude of S. coronal pole.	62.5	221.4	315.9	214.0
Approximate heliocentric longitude of N. coronal pole.	316.5	115.4	209.9	108.0
Heliocentric longitude of the earth at the eclipse.	336.0	101.7	90.9	206.8

This was accordingly done for the three coronas under discussion; then the model was projected upon a screen, and the lines of the wires carefully traced on paper. Finally these projected lines, including the poles of the sun's axis, earth's axis, axis of ecliptic, and the coronal

poles, S. E. K. C. respectively, were superposed upon the drawings of the eclipse, previously described as the dotted lines, where they appear on the charts 26, 27, 28 as heavy solid lines. Of course, the poles K. S. E. are located with no uncertainty, the only question pertaining to this investigation being the agreement of the poles C C′ of the model and photograph respectively. These are given as double lines, and it may easily be seen that their coincidence under three such diverse conditions is remarkable, taking both hemispheres into consideration. The line C is the axis of the model, located by computation only and therefore mechanically placed, since it may be predicted for any date, according to the ephemeris. The line C′ was drawn upon the eclipse photograph, and it is that line to which the central polar ray is apparently tangential, allowing a balanced curvature of the other rays on either side, by means of which a polar point was selected, and from which all the polar angles on the photograph were measured with the engine of the Transit of Venus Commission.

An intercomparison of these three charts shows a conformity in many respects between the model and the photograph of the corona which is interesting. There are some gaps in the available measured lines of the photographs, as the N. W. quadrant, January 1, 1889, and the S. E. quadrant, December 22, 1889, where the density of the light on the negative was too continuous to trace any rifts. Yet on the whole, it is instructive to find that the same model, constructed on a definite geometrical plan, should, by merely turning it into positions fixed by astronomical coordinates, agree even to this extent with the corona pictures. This is especially true of the poles C C′; of the accumulation of the rays to the right or left of the axis of the ecliptic K; and finally of the trend of the individual rays. One can be easily convinced that this conformity is not accidental by changing the location of the wires on the ball or by changing the assumed rotation period of 26.68 days.

Concerning the corona of 1893, for whose position I made a prediction, published in Astronomy and Astrophysics No. 119, it may be said that the photographs of that eclipse, kindly loaned by the Lick and the Harvard College observatories, were not such as to admit tracing out with certainty the coronal axis. This was due to the character of the corona occurring at the sun spot maximum, when the force producing the rays was apparently very turbulent; and to the fact that the rays were much burned on the film of the gelatine dry plate near the disk, whenever they were also taken at a distance from the moon's disk. It would be better to use wet plates in order to secure the same ray through a long radial distance. Composite rays are not adapted to accurate measurements without preliminary adjustments, which must be embodied in the computations. It seemed probable, however, on examination, that the axis of the corona as seen at the eclipse was on the side of the axis of the ecliptic required by my forecast, but the assertion could hardly be ventured. On the whole, viewing the entire

outcome of this corona work, it seems to harmonize well with the results of the data otherwise derived, but it will be desirable to continue the comparison in the future whenever practicable

THE SUN SPOT AREAS IN THE 26.68 DAY PERIOD.

The next compilation of data in the 26.68 day period naturally suggested is that of the spotted areas on the sun, in order to discover if there is any tendency to produce more spots on some meridians than on others. The observations available are: Carrington's Observations of the Spots on the Sun, November, 1853, to March, 1861, made at Redhill; Spörer's Beobachtungen der Sonnenflecken zu Anclam und Potsdam, January, 1861, to December, 1879; The Photographic Results of the Greenwich Observatory, 1878 to 1891; some other minor series being omitted in this discussion. In order to reduce to a comparable scale, certain observations taken at Washington, 1894–95, were made the standard. The radius of the sun's disk was 42 mm., and the photograph contained 5,542 square millimeters. Expressing results in $\frac{1}{100000}$ part of the visible disk,

1 square millimeter = 20 units for Washington.
1 square millimeter = 50 units for Spörer.
1 square millimeter = 20 units for Greenwich.
1 square millimeter = 18 units for Carrington.

The overlapping of the Spörer observations upon the Carrington series at one end, and the Greenwich series at the other, permits this comparison to be made. As no great exactness is required for our present purpose, which deals with relative numbers only, the work was done by placing a fine transparent scale, having a traced network of millimeter squares, upon the published diagrams of Carrington and Spörer and estimating the number of units covered by each spot. For the Greenwich results a catalogue of spots was constructed from which the areas were computed. The work now consisted in identifying the several spots on the sun with the dates of the solar ephemeris, assuming that the central meridian of the sun's disk falls upon the current date of that calendar system. If the spots did not happen to be upon the central meridian itself, then by the use of a scale the diagrams of spots could be readily assigned to the proper day of the period. Hence tables were constructed for the years 1854 to 1891, inclusive, in which each observed spot was entered under such a day of the period as was indicated by the 26.68 day ephemeris. Each year was then summed up by itself, and the total spotted areas, in units of the part of the disk, is recorded in Tables 34 and 35. The spots in the northern hemisphere of the sun were kept by themselves, and those in the southern hemisphere by themselves, throughout the compilation. The sum for the series of years is at the bottom of the tables, and shows the total area of spots on each day of the period; the sum for each year is at the side of the table, and shows the total spotted area during each entire year. Also

the variations by days on the mean for all the years is given in the lowest line of the tables. Dividing these variations by 20, the curves on chart 29 display the changes from day to day in the period. They are plotted in connection with the normal type curve already found from the study of the terrestrial magnetic field, so that the curve of spot variations for the southern hemisphere stands under the direct type, and for the northern hemisphere under the inverse type. If we admit that the southern spot curve has a slight tendency to fall to the

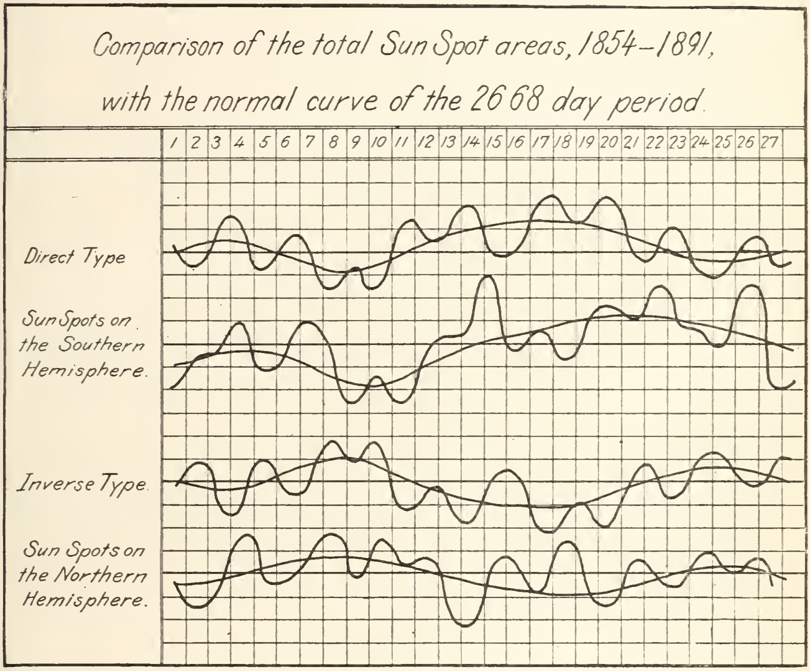


CHART 29.—Comparison of the total sun-spot areas, 1854–1891, with the normal curve of the 26.68-day period.

right of the direct-type curve, and the northern to the left of the inverse-type curve, it will be seen that there is a marked conformity between these curves. This occurs in the number of maxima and minima, which is the same; in the mean curvatures, which are distinctly inverted in the two types, and in the fact that the order of the crests is precisely the same throughout the entire curve. Furthermore, comparing curves 2 and 4, and making the suggested correction for sidling to the right and the left, the individual crests are opposed to each other throughout the traces.

TABLE 34.—*Sun-spot areas distributed in the 26.68-day period.*

NORTHERN HEMISPHERE.

Year.	1	2	3	4	5	6	7	8	9	10	11	12	13
1854	2	2	22	70	17	10	9	2	9	0	28	57	5
1855	0	0	14	23	17	0	0	25	0	0	0	0	0
1856	0	6	0	0	2	0	15	70	0	2	4	0	0
1857	70	0	0	49	10	33	35	16	16	45	50	0	30
1858	18	52	106	119	135	112	49	18	64	65	190	152	78
1859	74	63	77	76	59	121	78	39	82	148	36	39	102
1860	213	104	80	220	208	83	115	138	199	150	79	98	83
1861	25	120	90	78	208	84	174	185	85	115	115	30	41
1862	10	80	40	10	36	85	51	95	85	135	94	28	70
1863	26	80	10	28	19	60	57	0	30	122	185	210	140
1864	6	0	45	20	20	87	77	120	2	34	78	110	97
1865	2	39	42	23	57	32	43	25	62	0	25	20	47
1866	0	20	10	0	5	20	64	5	8	5	40	12	16
1867	0	0	0	29	0	8	6	5	5	0	0	9	0
1868	30	55	54	119	25	35	58	95	44	18	31	9	24
1869	120	61	65	175	83	45	100	44	40	123	101	46	87
1870	127	210	68	120	151	165	235	135	92	65	57	18	121
1871	123	30	28	44	60	18	84	92	65	113	74	88	74
1872	59	55	113	148	45	123	95	140	92	314	49	53	8
1873	30	18	107	56	20	29	20	29	159	22	111	50	0
1874	55	10	26	87	11	58	6	2	15	65	24	57	73
1875	45	27	3	0	12	20	0	4	18	26	2	0	22
1876	0	0	0	6	8	7	0	2	0	4	4	30	5
1877	30	0	0	0	4	0	0	59	30	90	30	20	0
1878	8	10	4	0	0	0	0	5	0	0	0	12	0
1879	3	0	5	0	0	45	31	0	2	0	15	4	0
1880	30	6	13	36	1	1	2	52	3	52	25	177	0
1881	120	32	70	66	12	31	85	2	36	69	43	114	83
1882	6	17	69	38	54	22	21	206	68	2	51	58	3
1883	8	70	74	63	1	23	33	83	3	0	11	59	23
1884	15	77	103	89	215	194	141	163	15	47	25	78	53
1885	172	39	1	0	11	1	7	76	202	43	75	17	7
1886	93	6	0	0	15	2	7	7	14	28	0	10	6
1887	1	5	12	26	18	9	0	1	4	1	1	4	2
1888	0	0	0	4	1	15	0	3	0	19	34	0	0
1889	0	0	2	4	0	0	0	0	0	0	0	0	0
1890	0	11	60	0	13	5	7	0	1	2	2	41	0
1891	81	68	5	175	28	60	24	64	67	36	64	24	54
Sum	1,602	1,373	1,518	2,001	1,581	1,643	1,729	2,007	1,617	1,960	1,753	1,734	1,354
Variation	−49	−278	−133	+350	−70	−8	+78	+356	−34	+309	+102	+83	−297

TABLE 34.—*Sun-spot areas distributed in the 26.68-day period.*

NORTHERN HEMISPHERE.

14	15	16	17	18	19	20	21	22	23	24	25	26	27	Sum.
3	76	20	28	20	17	53	44	34	14	12	0	22	8	584
0	0	0	0	10	11	0	5	0	0	14	16	0	0	135
4	25	0	0	5	0	8	9	0	36	17	5	0	0	208
19	0	0	20	2	48	39	12	0	10	52	25	33	48	662
47	30	43	80	65	145	47	25	14	87	177	62	81	4	2, 065
103	140	46	44	196	161	39	49	50	83	30	38	36	57	2, 066
63	31	154	85	154	48	117	228	142	72	159	255	111	90	3, 479
50	0	155	141	10	20	39	122	100	115	105	83	31	0	2, 321
100	25	120	40	8	14	30	23	43	40	52	26	160	34	1, 534
16	95	20	101	50	45	90	91	75	25	55	10	125	15	1. 780
40	60	40	0	20	32	112	42	10	40	65	100	80	32	1, 369
20	0	124	66	50	15	39	50	77	219	67	41	59	29	1, 273
0	0	23	10	15	14	23	23	14	19	10	0	38	25	419
0	32	40	0	30	8	0	18	39	70	0	0	6	0	305
60	146	30	50	18	0	15	35	60	10	40	23	43	8	1, 135
118	75	94	110	140	63	90	170	68	93	91	20	15	96	2, 333
108	130	65	82	57	105	106	233	100	57	190	230	103	126	3. 256
114	95	160	82	129	54	25	46	63	80	101	217	87	95	2. 241
58	69	134	65	169	109	33	125	172	125	140	110	61	110	2, 874
12	70	25	57	63	57	23	6	56	76	6	22	65	58	1, 247
38	7	5	40	4	6	38	2	46	31	20	28	24	34	812
0	41	37	1	6	12	4	0	20	27	14	2	17	18	378
2	2	0	0	22	0	0	0	4	0	10	7	0	5	118
0	0	0	35	0	4	40	0	15	0	0	0	0	30	387
0	0	0	3	0	0	0	0	0	0	0	0	0	0	42
2	3	0	0	20	0	0	0	0	0	0	3	0	5	138
5	79	0	171	46	148	22	16	21	0	17	50	0	2	975
32	33	88	45	128	38	36	111	85	106	65	53	81	93	1, 757
23	322	43	38	160	97	48	43	8	98	47	28	152	43	1, 765
35	31	31	15	106	89	80	21	33	34	25	90	17	178	1. 236
63	106	148	8	91	42	69	90	207	59	137	41	134	34	2, 444
0	23	9	7	106	48	12	61	32	3	16	16	74	30	1, 088
25	8	4	11	4	0	0	0	0	2	0	32	0	0	274
0	7	6	0	1	37	29	0	6	0	1	0	10	15	196
3	0	0	0	0	0	0	0	0	0	24	0	0	0	103
0	3	0	0	0	0	0	0	0	0	0	0	7	0	16
8	19	0	16	0	3	3	3	0	1	0	0	0	3	198
16	11	54	32	32	29	75	31	23	29	77	52	61	201	1, 473
1, 187	1, 794	1, 718	1, 483	1, 937	1. 519	1. 384	1, 734	1, 617	1. 561	1. 826	1. 685	1, 733	1, 526	44. 576
—464	+143	+67	—168	+286	—132	—267	+83	—34	—90	+175	+34	+82	—125	1, 651

TABLE 35.—*Sun-spot areas distributed in the 26.68-day period.*

SOUTHERN HEMISPHERE.

Year.	1	2	3	4	5	6	7	8	9	10	11	12	13
1854	0	3	0	4	5	43	65	12	6	4	0	0	0
1855	10	20	0	0	0	5	0	8	0	0	12	80	110
1856	0	0	0	0	8	6	0	0	0	25	0	0	15
1857	0	0	20	25	0	0	66	56	14	0	15	58	23
1858	33	90	5	27	12	25	26	13	0	109	12	66	37
1859	297	145	82	113	153	83	120	126	138	70	64	41	46
1860	115	90	114	106	82	144	119	40	101	190	56	96	55
1861	0	40	15	35	0	8	102	74	165	70	45	75	123
1862	35	77	193	131	93	0	39	55	18	40	78	21	53
1863	60	71	100	30	41	25	40	0	0	45	67	67	20
1864	0	56	142	156	152	0	110	98	0	5	45	55	15
1865	25	10	40	6	17	0	42	54	10	5	23	40	95
1866	0	2	15	0	14	30	2	9	29	25	0	8	0
1867	0	0	0	28	8	0	0	0	0	10	10	2	6
1868	0	106	32	43	91	53	15	30	100	12	19	34	47
1869	25	40	50	113	103	117	179	72	65	100	90	107	135
1870	110	93	90	138	66	23	113	177	157	130	86	209	135
1871	81	42	80	144	60	112	91	83	68	60	24	76	137
1872	60	60	62	117	135	107	229	119	18	103	70	37	64
1873	36	92	68	55	27	85	92	55	28	25	4	81	7
1874	48	60	25	63	23	25	5	105	4	56	40	4	50
1875	0	4	22	18	4	0	0	4	8	4	0	8	76
1876	35	16	18	65	38	9	4	8	0	8	31	8	12
1877	5	0	0	0	0	0	5	0	12	4	28	10	2
1878	0	9	15	15	0	4	31	0	0	17	15	30	0
1879	6	10	10	17	15	6	18	3	9	5	2	0	0
1880	4	0	2	42	24	4	0	13	74	3	0	25	1
1881	27	73	46	19	26	36	35	30	0	1	0	11	47
1882	32	10	44	31	100	2	95	3	34	92	48	35	46
1883	52	150	136	66	64	196	39	275	39	26	95	57	70
1884	6	16	19	91	49	61	65	19	18	84	90	43	81
1885	129	63	50	24	18	102	97	85	29	58	59	18	151
1886	57	16	13	106	12	4	5	9	1	3	10	4	3
1887	11	33	32	7	3	80	0	5	0	0	1	1	1
1888	4	2	6	8	0	21	22	1	4	0	0	7	0
1889	0	6	0	1	0	0	7	0	6	0	0	34	20
1890	2	6	12	12	4	87	6	0	0	0	0	1	0
1891	2	102	9	9	11	60	3	9	22	6	6	44	67
Sum	1,307	1,613	1,567	1,865	1,458	1,563	1,887	1,650	1,175	1,395	1,145	1,493	1,750
Variation	—384	—78	—124	+174	—233	—128	+196	—41	—516	—296	—546	—198	+59

TABLE 35.—*Sun-spot areas distributed in the 26.68-day period.*

SOUTHERN HEMISPHERE.

14	15	16	17	18	19	20	21	22	23	24	25	26	27	Sum.
0	6	25	0	0	0	3	0	0	51	7	4	0	0	238
15	0	0	8	0	0	3	10	0	9	0	0	0	12	302
4	0	0	0	8	0	0	0	0	0	0	0	0	0	66
30	50	10	0	8	56	8	97	0	68	47	0	0	20	671
55	25	28	15	14	37	57	16	15	10	9	30	38	8	812
112	111	60	120	50	39	112	45	134	67	192	82	89	94	2,785
98	367	153	210	115	101	163	105	150	100	160	210	96	42	3,378
78	160	50	35	12	76	136	158	28	105	79	108	76	86	1,939
37	8	51	0	28	76	153	81	45	40	61	79	138	81	1,711
20	32	52	35	5	118	10	35	225	132	57	22	90	73	1,472
37	42	40	25	0	90	45	68	80	15	35	20	55	0	1,386
55	55	50	62	65	25	0	0	0	25	0	20	8	0	732
22	0	2	24	26	36	12	0	0	20	0	0	15	3	294
0	30	44	38	16	20	0	0	5	20	20	16	10	0	283
90	60	50	80	120	55	81	110	20	95	85	38	10	56	1,532
124	87	83	0	132	90	58	77	88	23	61	155	196	232	2,602
147	179	155	157	88	132	128	110	128	60	162	175	172	57	3,377
199	197	56	91	119	60	97	129	105	111	85	90	51	25	2,473
76	64	120	92	60	212	167	108	155	99	104	40	62	55	2,595
7	48	36	76	44	33	56	20	35	14	137	206	43	8	1,418
3	72	0	36	92	40	59	23	71	30	50	24	28	18	1,054
13	6	26	4	0	20	2	0	0	29	0	31	9	0	286
12	15	15	4	5	8	0	0	0	0	2	0	0	6	319
35	10	0	23	0	2	0	0	20	15	30	0	45	0	246
0	10	10	0	0	0	0	0	0	0	0	0	0	0	156
0	17	2	12	22	0	0	0	0	0	0	2	2	0	158
24	14	66	102	98	0	10	23	1	23	0	3	53	8	617
96	83	19	23	114	18	24	7	57	46	60	9	16	19	942
145	7	194	113	76	132	160	126	125	15	26	72	134	12	1,909
150	102	26	267	29	156	221	44	252	234	102	29	219	38	3,134
28	113	14	15	59	74	71	71	139	41	10	9	26	59	1,371
38	96	72	2	82	31	55	72	11	30	105	167	466	166	2,276
7	111	42	53	19	83	102	221	85	96	71	3	10	13	1,159
1	9	42	35	1	7	17	34	70	8	25	0	2	104	529
0	4	9	20	35	17	1	55	22	68	0	1	0	0	307
14	11	0	0	11	35	6	50	52	0	4	0	7	7	271
0	0	0	1	2	0	0	1	30	14	20	0	0	6	204
7	70	26	5	1	8	0	7	13	123	12	0	24	0	646
1,779	2,271	1,628	1,783	1,556	1,887	2,017	1,903	2,161	1,836	1,818	1,645	2,190	1,308	45,650
+88	+580	−63	+92	−135	+196	+326	+212	+470	+145	+127	−46	+499	−383	1,691

When this result was first obtained, I hoped to find in it a clew to the law of the inversion of the type curve detected in the earth's field, but a persistent study of the possible physical relations of such curves to positive and magnetic fields failed to disclose any rational explanation of the connection along these lines, and this phenomenon is therefore left to stand by itself for what it is worth. It is certainly a remarkable coincidence, if in reality it is nothing more. There may be some reason in the physics of the sun why the spots tend to form along the several meridians, with excess and defect on the same meridian in the opposite hemispheres, due to the so-called positive and negative magnetism, but no definite suggestion is here advanced. Regarding the sidling to the right and left there is more to be said, because, as already shown, the south coronal pole appears to stand a quadrant in advance of the northern, so that the magnetic meridians should be drawn downward and to the right across the disk, causing southern spots to be in advance and northern behind the point where the magnetic meridian crosses the solar equator. This also is stated merely as a suggestion available in a further study of this curious question. Of the main fact there seems, however, to be no doubt, namely, that a distinct tendency exists to form spots more frequently or larger on certain meridians than on others, and that the representative curve conforms very closely to the typical curve of the 26.68-day period.

THE VARIATIONS OF LATITUDE IN CHANDLER'S PERIOD.

The relative numbers, taken year by year, also require a few remarks. They show the sun-spot frequency on the scale adopted above. If we extract from Jahrbuch der Astronomie u. Geophysick, III, 1892, p. 14, the relative sun-spot numbers of Wolf, for the years 1830 to 1892, and supplement them with those given in *Terrestrial Magnetism*, Vol. 1, No. 3, p. 150, the annual numbers yield the well-known curve given on chart 30. The second curve of the same is plotted from the numbers of Tables 34 and 35. It shows a little less clearly the tendency to superpose a $2\frac{3}{4}$-year period, already mentioned in the preceding chapter, upon the 11-year period. The third curve is derived from Chandler's formula for the secular variations of the latitude of the earth's pole of rotation, as deduced from his discussion of the variations of declination of star places, during the past century. The formula is $\varphi - \varphi_0 = -0.10'' \cos (t-1830)\, 30^{\circ}$, and it gives maxima in 1836, 1848, 1860, 1872, 1884, 1896, with minima in 1842, 1854, 1866, 1878, 1890.

I am not in a position to judge how reliable the factor 30° is, upon which the recurrence of the maxima and minima depends. Inasmuch as Chandler's observational data are of greater value since the year 1830, and of less accuracy in the eighteenth century, the evident agreement of the sun-spot curve with the latitude curve for half a

century is suggestive of some physical connection. If the 30° were to be better replaced by 31.5°, then the curves will coincide for an immense length of time; as it is, they will run off and coincide again in 20 periods, 225 years. Now, since the proposed explanation of Chandler's secular 12-year period of latitude variations does not show how this synchronism can occur, it may be remarked that the physical properties of the solar magnetic field developed above are entirely in favor of such a terrestrial effect as the one found in astronomical observations. For if the magnetic field in the neighborhood of the earth increases in strength with the sun-spot period, which is unquestioned, then the earth, being immersed in it, will be subject to proportionally stronger couples, tending to bring the axis of its magnetization parallel to the mean direction of the external field. As this is opposed by the forces producing procession and mutation, we have the resulting swing of the earth's axis of rotation relatively to some nor-

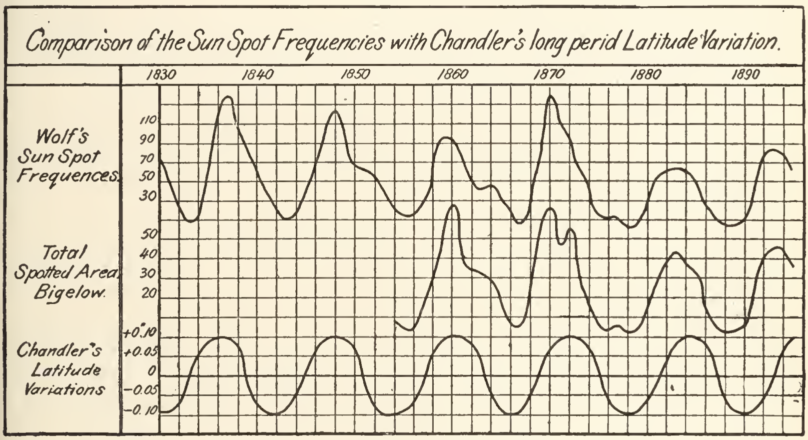


CHART 30.—Comparison of the sun-spot frequencies with Chandler's long-period latitude variation.

mal fixed direction. If the Chandler period can be reduced to agree with the sun-spot period, this conclusion will be decidedly the best explanation of the phenomena. A computation from astronomical data of the force required for this effect may also afford another determination of the strength of the solar magnetic field outside the earth.

THE LAW OF THE INVERSION OF THE NORMAL TYPE CURVE.

The next problem to consider is the law of the phenomenon of inversion of the normal type curve, which has been shown to have an intimate connection with the position of the trace of the sun's axis of rotation upon the plane of the ecliptic. The direct type prevails when the earth is in the quadrants whose centers are parallel to this trace, and the inverse type in the quadrants whose centers are perpendicular to the plane of the sun's axis—the former therefore central March 6

and September 6 at right angles to the nodes of the sun's equator, the latter central June 5 and December 5, upon the line of these nodes. This conclusion depends solely upon the validity of the 26.68-day ephemeris, the correctness of the normal curve, and a careful matching of it with the observations of the terrestrial magnetic and meteorological elements recorded in each period.

The solution is approached by analyzing the lines of force of a distant spherical magnet whose axis coincides with that of the sun's axis of rotation, the positive pole being to the northward of the plane of the ecliptic. An isolated positive magnetic unit mass is assumed as the exploring point, which, if free to move, will traverse the lines of force from the north side to the south side of the ecliptic, and thus reach the earth upon its northern hemisphere. The same unit mass would trace the course of the lines in the earth's magnetic field from the southern into the northern hemisphere—that is, in the opposite direction to the sun's lines. In order to draw the line or tube that leaves the sun and finally embraces the earth at a given instant, or would contain the earth constantly if the rotation of the sun was of the period 365.25 days, we have the formula,

$$N = 2\pi \left(\tfrac{4}{3}\pi\, R^3\, I\right) \frac{\sin^2\theta}{r};$$

or regarding the moment

$$M = VI = \tfrac{4}{3}\pi\, R^3\, I = \text{unity},$$

for a type diagram,

$$N = 2\pi . \frac{\sin^2\theta}{r}.$$

For the determination of the constant N,

$$\frac{R = \text{radius of the sun}}{r = \text{the distance of the earth}} = \frac{1}{214.4}.$$

Hence, for $R = 1$, $\theta = 90°$ and $r = 214.4$, $N = 0.02936$.

To complete points along the line N:

θ	Log $\sin^2\theta$.	Log r.	r.
°			
0	....	....	....
10	18.47934	0.81056	6.5
20	19.06810	1.39932	25.1
30	19.39794	1.72916	53.6
40	19.61614	1.94736	88.6
50	19.76850	2.09972	125.8
60	19.87506	2.20628	160.8
70	19.94598	2.27720	189.3
80	19.98670	2.31792	207.9
90	20.00000	2.33122	214.4

The points plotted from these coordinates ($r.\ \theta$) in each quadrant produce the curve of chart 32 from the center, O, and this system of magnetic ovals shows the curvature of the lines in space between the sun and the earth. The length of these lines between the sun and the earth is 92,834,000 miles multiplied by $\frac{3}{2}$, or 139,251,000 miles, as can be found by integrating the curve from 0° to 90°, for N, r, given above. The transmission of magnetic energy, therefore, is along a path three-halves the length of that of the linear electro-magnetic radiation for the force affecting the earth. Of course the interplanetary spaces are filled with the same kind of energy, decreasing in intensity from the sun outward in the ratio of the inverse cube of the distance, and it is therefore considerably greater in the neighborhood of the planets Venus and Mercury.

Since the axis of the sun, S, is inclined to the axis of the ecliptic, K, at the angle 7°, and as before indicated the pole of the corona is located at 5° from the sun's poles, the result follows that in the course of the year the earth occupies points along the curve ($r.\ \theta$) from 0° to about 12° each side of the longest diameter of the ovals. To compute the angles at which these solar lines approach the earth, in extreme positions, we may take for illustration radii making the angles 10° from the diameter. The components of magnetic force emanating from a close doublet are—

$$PA = 2\ M\ \frac{\cos\theta}{r^3} \text{ along the radius.}$$

$$PB = M\ \frac{\sin\theta}{r^3} \text{ perpendicular to the radius.}$$

PC=resultant force, whose direction is required, being the tangent to the oval at P. (Chart 32.) Constructing a close doublet AB (Chart 31), the demonstration proceeds as there written, following J. J. Thomson, Elements of Electricity and Magnetism.

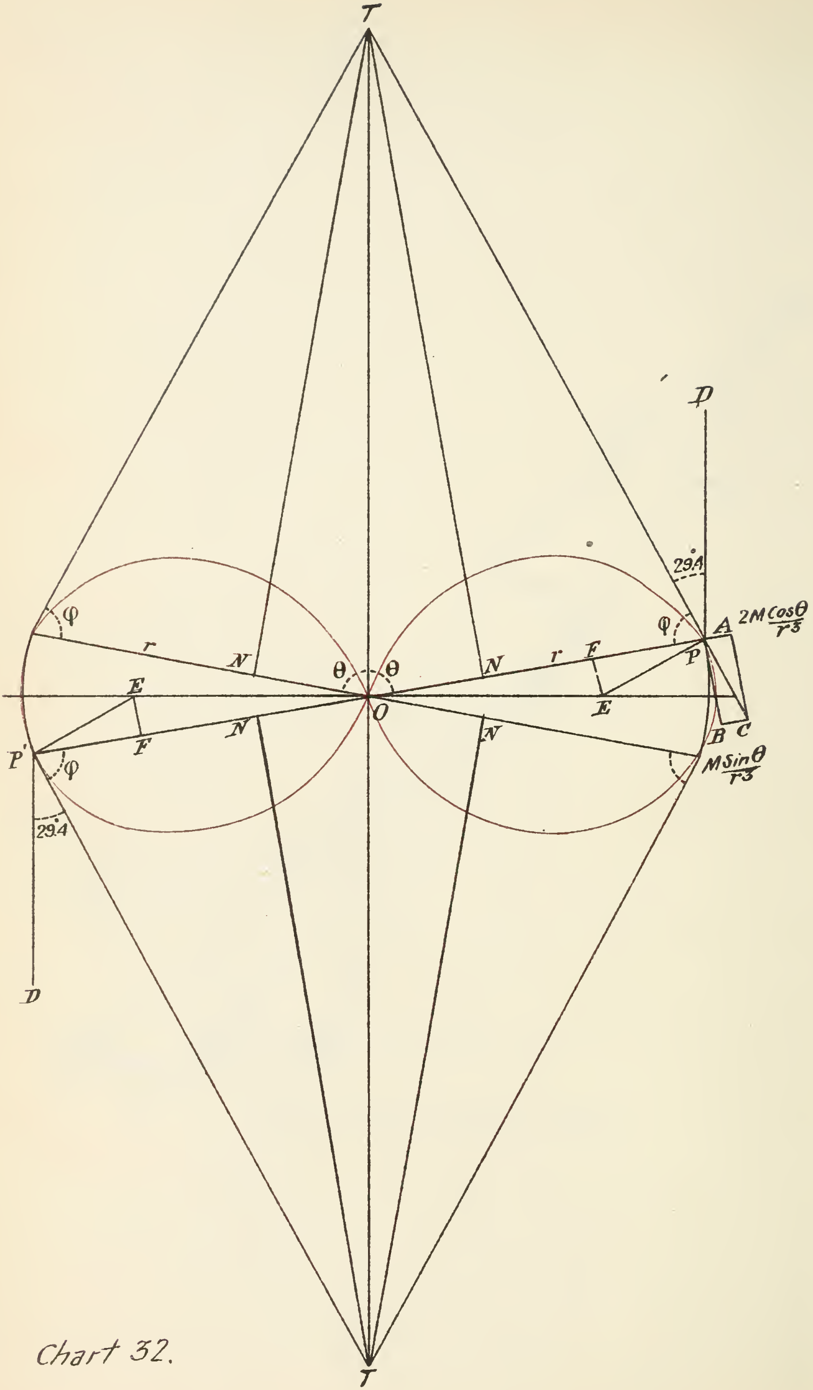

T
D
29.4
φ
A
$2M\frac{Cos\theta}{r^3}$
r
N
F
P
θ
θ
E
O
B
C
P'
$M\frac{Sin\theta}{r^3}$
D

Chart 32.

RESOLUTION OF FORCES IN A DOUBLET.

$$\text{Along AP} = +\frac{e}{r_1^2}.$$

$$\text{Along BP} = -\frac{e}{r_2^2}.$$

$$\text{Along OP} = \frac{e}{r_1^2}\cos \text{APO} - \frac{e}{r_2^2}\cos \text{BPO}.$$

$$= \frac{e}{r^2}\left(1 + \frac{2a}{r}\cos\theta\right) - \frac{e}{r^2}\left(1 - \frac{2a}{r}\cos\theta\right).$$

$$= 4\,a\,e\frac{\cos\theta}{r^3} = 2\,\text{M}\frac{\cos\theta}{r^3}\text{ approximately.}$$

$$\text{Along PD} = \frac{e}{r_1^2}\sin\text{APO} + \frac{e}{r_2^2}\sin\text{BPO}.$$

$$= \frac{e}{r_1^3}\,a\sin\theta + \frac{e}{r_2^3}\,a\sin\theta.$$

$$= 2\,a\,e\sin\theta = \text{M}\frac{\sin\theta}{r^3}\text{ approximately.}$$

$$\cos\text{APO} = \cos\text{BPO} = 1 \text{ for small angle.}$$

$$\sin\text{APO} = \frac{\text{AE}}{\text{AP}} = \frac{a\sin\theta}{r_1}.$$

$$\text{AP} = \text{OP} - \text{AO}\cos\theta.$$

$$r_1 = r - a\cos\theta.$$

$$r_1^2 = r^2 - 2\,a\,r\cos\theta + a^2\cos^2\theta.$$

$$\frac{1}{r_1^2} = \frac{1}{r^2} + \frac{2\,a}{r^3}\cos\theta\text{ approximately.}$$

$$\frac{1}{r_2^2} = \frac{1}{r^2} - \frac{2\,a}{r^3}\cos\theta\text{ approximately.}$$

Then Gauss's theorem becomes (chart 32),

$$\tan\varphi = \tan\text{OPT} = \frac{\text{TN}}{\text{PN}} = \frac{\text{PB}}{\text{PA}} = \frac{\text{M}\sin\theta}{r^3}\cdot\frac{r^3}{2\,\text{M}\cos\theta} = \tfrac{1}{2}\tan\theta = \frac{\text{TN}}{2\,\text{ON}}.$$

$$\text{PN} = 2\,\text{ON}. \qquad \text{OP} = 3\,\text{ON}.$$

As this relation holds constantly on the curve whose coordinates are $r\ \theta$, a graphic construction is effected by taking $\text{ON} = \frac{1}{3}\,r$, drawing a perpendicular from N upon OT, and joining PT, which is the tangential direction required. Since the angle φ rotates through 180° while θ changes 90°, the curvature of the oval is rapid.

For $\theta = 80°$, $\tan\theta = 5.6713$, $\tan\varphi = 2.8357$, $\varphi = 70°\ 34' = \text{OPT}$. OPD $= 100°$, and TPD $= 29°\ 26'$. Similarly other angles for assumed values of θ may be found. The direction of the radius of curvature at any point is obtained by drawing from F, where $\text{PF} = \frac{1}{3}\,\text{PO}$, a perpendicular upon the diameter at E, and connecting PE; then the length of the radius of curvature is found by the usual formula. It is preceived that at the opposite points, PP^1, our exploring magnetic mass runs parallel, and therefore the lines of the solar field at these points are directed parallel to each other, making thus an angle of about 30° with the direction, PD, of the axis of polarization.

CHART 32.—Application of Gauss's theorem to the construction of a magnetic oval at the point, $r = 208$, $\theta = 80°$.

Now consider the actual relations between the sun and the earth. Let K=pole of ecliptic, S=pole of the sun, E=pole of the earth, in the astronomical triangle at the center of the sun on Chart 33. EKS is turned upward through a right angle, about KS, into the plane of the paper for convenience of drawing. The following well-known angular relations exist:

F=angular distance between the sun's equator and the earth's equator.

D=angular distance between the sun's equator and the ecliptic.

EOK=G=angle at O between poles K and E.

KOS=H=angle at O between poles K and S.

tan F=tan ω sin ⊙.

sin D=sin I sin (⊙—N). For F and D, +=south; —=north.

tan G=tan ω cos ⊙.

tan H=tan I cos (⊙—N). For H and G, +=east; —=west.

I=7° 15′. N=74° 0′. ω=23° 27′.

Values of H G D F.

Date.	H	G	D	F	Date.	H	G	D	F
	° ′	° ′	° ′	° ′		° ′	° ′	° ′	° ′
January 1	—6 28	4 41	—3 16	—23 4	July 1	6 32	— 4 8	3 8	23 10
February 1	—3 49	16 19	—6 10	—17 45	August 1	4 9	—15 20	5 57	18 35
March 1	—0 25	22 16	—7 14	— 8 10	September 1	0 38	—22 3	7 13	8 50
April 1	3 22	23 2	—6 26	4 57	October 1	—3 0	—23 14	6 37	— 3 35
May 1	6 5	18 10	—3 57	15 30	November 1	—5 58	—18 36	4 9	—15 18
June 1	7 14	8 4	—0 23	22 17	December 1	—7 14	— 8 42	0 35	—22 5

In the course of the revolution of the earth about the sun KS is seen under the varying angle H, whose maximum is 7° 15′; KE is seen under the varying angle G, whose maximum is 23° 27′, and SE is seen under the varying angle (H + G), whose maximum is 26° 20′. Viewed from the earth on June 5 and December 5, (H + G) = (7° + 8°) = 15°; and from the earth on September 6 and March 6, (H + G) = 22°. On the former dates our sight line is perpendicular to the plane KOS; on the latter it is in the plane KOS. These are two extreme positions to which our exposition may be limited, other dates being proportionally related to them.

According to our supposition, OS represents the mean position of the axis of the coronal field during one rotation of the sun on its axis, and it will therefore be temporarily taken for the axis of magnetization of the sun. Constructing the magnetic ovals for March 6 and September 6, and conceiving the same system to be rotated about the axis OS, through 90° for the dates June 5 and December 5, the plane of the ovals for these dates is represented on the diagram by the trace OS, and the curvature involving the earth is that of the ovals near the extremity of the diameter. Throughout the motion of the earth in the orbit its mean magnetic axis may be taken to coincide with the axis of rotation, for the mean of the 24-hour components employed in

CHART 33.—Relation of the lines of the magnetic ovals to the earth's axis at four points in the orbit.

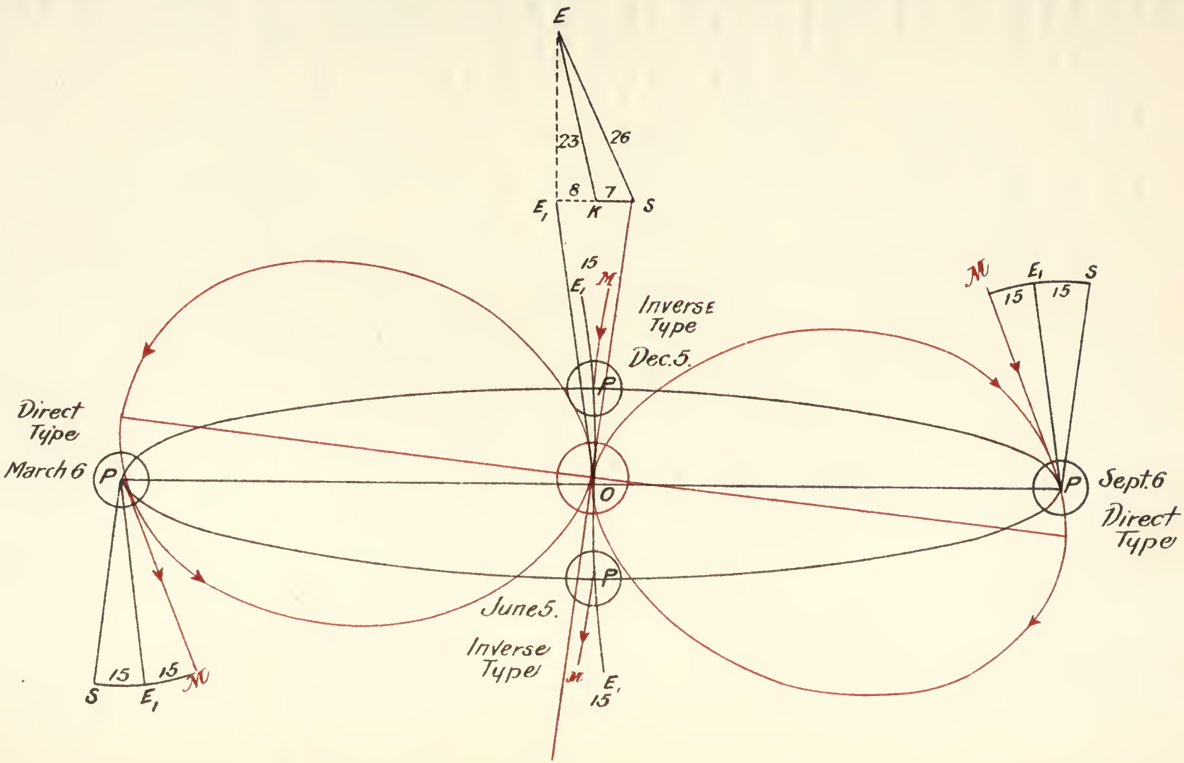

E
23
26
8
7
E1
K
S
15
E1
M
Inverse Type
Dec. 5.
M
E1
S
15
15
Direct Type
March 6
P
P
O
P
P
Sept. 6
Direct Type
June 5.
Inverse Type
M
E1
15
S
15
E1
15
M

Chart 33.

the computation—that is, the average composition of the forces acting on the earth during twenty-four hours—lies in lines always parallel to OE in its true spacial position. The components at the earth may be resolved into KE_1 and EE_1. The component EE_1 at the earth is expressive of the facts that all magnetic lines are perpendicular to the plane of the ecliptic except in the planes passing through the center of the sun, and that these external lines fall upon the earth primarily at 22° from its axis of rotation. The phenomenon of distortion by a permeable shell is omitted here from consideration; the axis of the undisturbed external field will touch the earth at 22° from the geographical axis and describe a circle about it daily. This may be closely connected originally with the location of the axis of the principle magnetic moment of the earth at about 23° from the poles of rotation and having a period of three thousand one hundred and forty-seven years.[1] Practically, as already shown in a preceding chapter, the magnetic lines are distorted, and they spread out over the earth from the center of the auroral ovals.[2] For purposes of our subject of inversion this 22° component EE_1 can be laid aside, because it is evidently constant throughout the year, in consequence of the earth carrying its axis stiffly through the magnetic field always parallel to itself; the component E_1K is the variable one to consider.

With the other component E_1K the case is entirely different, since the curvature and position of the ovals now become the leading consideration. As already shown, the September 6 position is above the diameter of the oval on the average 7°, which rises to 12° during the rotation of the coronal field, its pole being 5° from sun's axis. At $\theta=83°$, $\varphi=76° 12'$, and hence MPS (Chart 33)=TPD (Chart 32)=21°; for $\theta=80°$, MPS=30°. Since $SPE_1=H+G=15°$, we have MPE_1 varying from 6° to 15°, so that the magnetic lines always fall on the earth upon the same side of the plane EOK containing the earth's axis. At March 6 the earth is below the diameter of the sun's magnetic ovals, but precisely the same facts hold true regarding the positive magnetic exploring pole which approaches the earth along the line MP, being parallel to the September line PM.

As the earth passes along its orbit, from March 6 it gradually approaches the diameter of the ovals and reaches it on June 5. The magnetic lines are perpendicular to the radius vector there, since for $\theta = 90°$, $\varphi = 90°$, but the plane containing the magnetic line is now parallel to SO, which makes the angle $SOE_1 = 15°$ with the plane of the earth's axis, now, however, on the opposite side of it from the March date. In the same way at December 5 the magnetic field is again parallel to SO; MO for June 5 and December 5 is drawn parallel to SO.

We have thus shown that the only variable component of the solar magnetic field effectively approaches the earth from north to south,

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[1] V. Carlheim-Gyllensköld, L'attraction Magnétique de la Terre, p. 24.

[2] Van Bemmelen.

first on one side of the plane of the earth's axis, in March and September, and second on the opposite side, in June and December. The effect is to place the earth as a magnetized sphere in two sets of opposite couples during the course of a year, and we have only to trace out the action of such couple systems of magnetic forces within the earth's field to show that the observed phenomenon of inversion of the curve of typical strength of the solar field from meridian to meridian is a direct consequence of such shifting of the direction of an external field. The case may be summarized by saying that the inverse type is the one due to the magnetic action in the plane of the ovals inclined at an angle SOE_1 to that component of the earth's axis resolved perpendicular to the plane containing the trace of the sun's axis, POS, and the direct type of the effect of the curvature of the ovals themselves in their own planes. The same sequence would be found by turning the arc of the oval about an axis and sliding the point of contact up and down the line of force as required by the astronomical coordinates.

It may be remarked that the fact of the discovery of the direct type in the computation before the inverse type, is due to the somewhat stronger magnetic force prevailing for the couples in March and September; and the fact that the inverse type is rather more firmly developed in the magnetic and the meteorological curves is because the field itself is inclined at a larger effective angle for the couples in June and December. The peculiar penumbra of uncertainty in passing from one quadrant to the other, from the direct to the inverse periods, shown on chart 19, which constituted the great difficulty in detecting the fundamental law, is clearly due to the action of the solar magnetic lines being then very nearly in the plane of the earth's effective axis, and thus producing no steady distortion of the earth's field by the couple. Of course, any irregularity in the solar output, any swaying about of the field in space must show itself in a corresponding irregularity at the earth. The employment of the mean of the 24-hour observations eliminated to a large extent this source of confusion and enabled us to find an approximate normal field during a rotation of the sun on its axis. Abnormally large disturbances occur in consequence of spasmodic outbursts of the sun conveying energy to all the interplanetary spaces and setting up an unusually strong field of magnetic force, which, being impressed upon the earth's field, is measured in the components H D V at the several stations.

Having arrived at the conclusion that an external field of force directed alternately from opposite sides of the axis acts upon the earth's magnetic field, we have to inquire what the effect is in detail upon the lines of the earth's field at all stations of the earth simultaneously. It is not sufficient to consider the mean effect upon the earth as a magnet acted upon by a couple taken as a whole, but the deflections of the lines throughout the medium surrounding the earth must be studied in detail, because our magnetic observations are made at individual points

of such a disturbed medium, and it is the effect of these couples upon the H D V of each station that is required. According to the preceding analysis we have (1) an external field, (2) an induced doublet or equivalent uniformly magnetized sphere whose forces are, if H is parallel to the axis x,

$$
(2)\quad
\begin{aligned}
{}^{i}X^{e}_{e} &= \mp R^3 \frac{\mu-1}{\mu+2} H. \ \frac{1}{r^3}\left(1-\frac{3\,x^2}{r^2}\right)+H. && \text{Inflected system.} \\
& && \text{Exflected system.} \\
{}^{i}Y^{e}_{e} &= \mp R^3 \frac{\mu-1}{\mu+2} H. \ \frac{1}{r^3}\left(1-\frac{3\,x\,y}{r^2}\right). && \text{"} \\
{}^{i}Z^{e}_{e} &= \mp R^3 \frac{\mu-1}{\mu+2} H. \ \frac{1}{r^3}\left(1-\frac{3\,x\,z}{r^2}\right). && \text{"}
\end{aligned}
$$

for points in the external field; the inflected system being applicable to the equatorial portion of the magnetic shell of the earth, and the exflected system to the polar regions; the induction of the doublet being approximately parallel to the axis of the external field, which therefore shifts with the seasons of the year; (3) the permanent internal field of the earth,

$$
(3)\quad
\begin{aligned}
X &= -\frac{4}{3}\pi R^3 I \frac{1}{r^3}\left(1-\frac{3\,x^2}{r^2}\right) \\
Y &= +\frac{4}{3}\pi R^3 I \frac{1}{r^3}\left(\frac{3\,x\,y}{r^2}\right) \\
Z &= +\frac{4}{3}\pi R^3 I \frac{1}{r^3}\left(\frac{3\,x\,z}{r^2}\right)
\end{aligned}
$$

The formation of formulæ (2), (3) has been already indicated in chapter 3. A further analytic development of the coefficient $R\frac{\mu-1}{\mu+2}H$, occurring under (2) may be added at this place.

If a permeable mass is placed in an external field a doublet is induced of opposite polarity to the direction of the external field. The state of an external field at any instant may be analyzed by superposing upon a normal field another variable field, inducing internal doublets, alternately in opposite directions, according as the actual field is greater or less than the normal field. The observed variations $\triangle$D, $\triangle$D, $\triangle$V in the earth's magnetic field may thus be regarded as the components of a secondary force superposed upon the earth's steady normal field. The case before us supposes no permanent secondary internal magnetization, and is therefore applicable to the earth's shell; the field magnetized in the earth's nucleus remains meanwhile steady, except for its secular variations of long period.

RESOLUTION OF FORCES IN AN INDUCED DOUBLET.

$$QC = AB = -M\frac{\sin\theta}{r^3} = -H\frac{\mu-1}{\mu+2}\ \frac{R^3}{r^3}\sin\theta$$

$$QD = FE = +2M\frac{\cos\theta}{r^3} = 2H\frac{\mu-1}{\mu+2}\ \frac{R^3}{r^3}\cos\theta$$

$$\begin{aligned} GE &= BQ = H\sin\theta \\ EQ &= \quad\ \ H\cos\theta \\ DS &= QL = H_1\sin\theta \\ QD &= LS = H_1\cos\theta \end{aligned}$$

$$AQ = QL = H\sin\theta - M\frac{\sin\theta}{R^3} = H_1\sin\theta. \quad \text{Tangential.}$$

$$FQ = \mu\, LS = H\cos\theta + 2M\frac{\cos\theta}{R^3} = \mu\, H_1\cos\theta. \quad \text{Normal.}$$

$$H - \frac{M}{R^3} = H_1 \qquad H + \frac{2M}{R^3} = \mu H_1$$

$$H_1 = \frac{3H}{\mu+2} \qquad M = \frac{H(\mu-1)}{\mu+2}R^3.$$

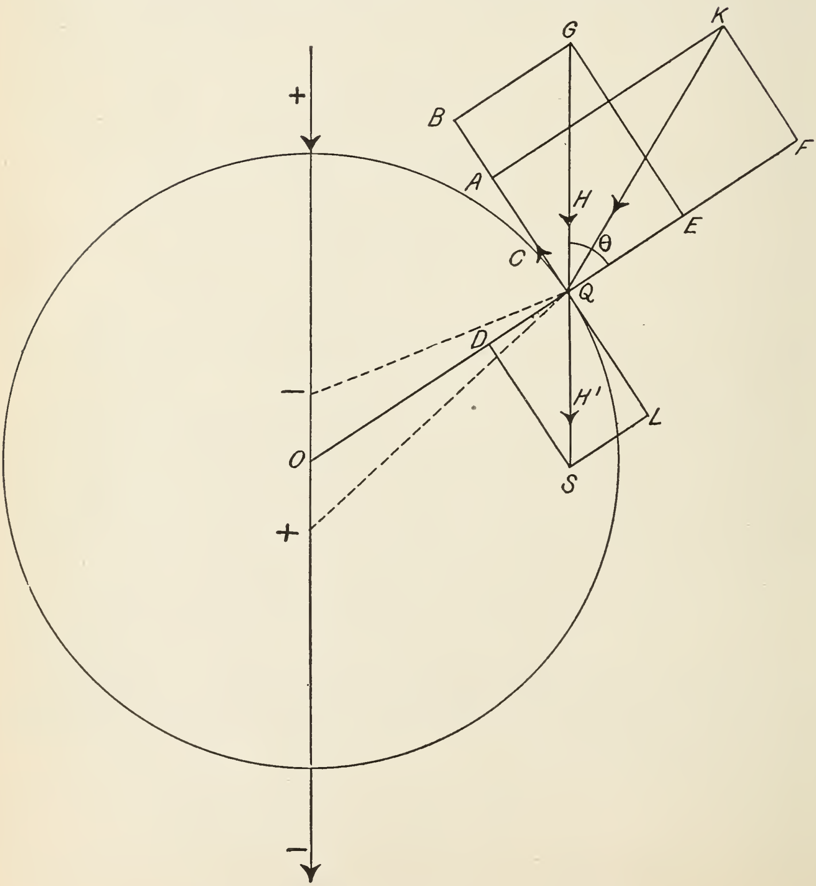

CHART 34.—Resolution of forces in an induced doublet.

The external field is deflected to pass through the permeable mass. Pursuing this analysis to all points in the neighborhood of the sphere, also including the exflected case of an impermeable nucleus, we have a distribution of force shown on Chart 8, of which additional details are given on Chart 12.

By means of these formulæ any possible case can be solved in detail, but as our purpose is to explain general ideas, we will pass to some empirical diagrams which show at a glance the deformation of a magnet field when placed in several standard positions within the external field of force.

It may be remarked once more that if an ideal distribution of the earth's magnetization be assumed, such as a uniform internal force parallel to an axis, either the axis of the earth's rotation or the axis of its magnetization, a certain type of normal force must be developed, derived from a potential, to which the observed H. D. V. over the earth correspond. If this same magnetized sphere be placed in an external field the normal field will be permanently changed by the superposition of an induced doublet. In our special case of a central sphere and superincumbent spherical permeable shell the deformation of the normal field will be such as is indicated by the curve of intensity of the impressed field (Chart 11). That, however, should be inverted from the position there given, because the strong impressed external field will make depressions in the resultant field, referred to a simple normal field. The problem of the Gaussian Harmonic Analysis must therefore fully take account of those two fields, and also the induced currents arising from their variations in strength, or from their relative motions in space.

The following typical charts (35 to 39 inclusive) of the lines of force surrounding a magnet, placed at different angles to the horizontal component of the earth's field, were constructed by moving a small exploring magnet compass so as to be constantly tangent to the lines, and tracing out the course of successive lines about a magnet of the following dimensions:

Moment of inertia of the bar,

$$T=\left(\frac{l^2}{12}+\frac{r^2}{4}\right)P \quad cm^2gr=675.27$$

Magnet moment,

$$ma=M=\pi^2n^2\frac{T}{H}S^2=1080.$$

where

$l=11.5$ c. m.	length of magnet.
$r=0.45$ c. m.	semidiameter.
$P=61$ grams.	weight.
$n=\frac{11}{60}=0.18.$	number of half swings per minute.

$H=0.20.$	earth's horizontal component.
$a=\frac{5}{6}l=9.6$ c. m.	the effective distance between the magnet poles.

Hence

$m=112.4\ C.^{\frac{3}{2}}\ G.^{\frac{1}{2}}\ S^{-1}$	units of pole strength.
$F=4\pi m=1413.$	number of lines sent out by the pole.

The external field can also be traced by the usual graphic methods.

The small exploring magnet is itself under a feeble couple from the earth's field, but this can be easily eliminated by making the resulting curve the mean of the branches on opposite sides of the axis. Mark a diameter carefully on the base of the case of the exploring magnet, which was 2.5 cm. long on the one employed; start at any arbitrary point on the large magnet placed exactly parallel to the direction of the earth's field; allow the exploring needle to swing freely, and rotate the marked diameter of the box till it is parallel to the needle; plot in the other end of the diameter, which will be a second point on the same line of force; transfer diameter of the compass to begin at this point, make tangent the needle and diameter, and thus plot a third point. In this way the following diagrams were made, here reproduced on a smaller scale.

The positions of the earth's field and the magnet are marked on each chart. Chart 35 gives the field in its stable position, and shows the lines running from the ends of the magnet off into space, where they are continued into and join upon the lines of the external field. Compare inner portion of Chart 6.

Chart 36 gives the unstable position of the magnet in the field, and indicates that it is so because all the lines of force are closed, returning into the magnet itself. Compare Chart 7. The least movement of the magnet away from this position will release some lines to run into space, and this produces an effective couple, which will turn the magnet, when free to move, into its stable position. If the charts 35, 36 are superposed, we shall see the extreme deformations of the normal field, which were displayed on Chart 8. In the first case, the effect of an external field is to expand all the lines outside the position which they occupied when the magnet was screened from all external fields; in the second case, the lines are all contracted within these normal lines. The effect of an external field directed from magnetic S to N on the magnet is to expand the field as a whole, and that is the same thing as a decrease of the horizontal force everywhere, an increase of the vertical force everywhere, and deflection of the declination, if the lines of the field are not parallel to the external meridians of the magnet. If the external field is directed from N to S along the magnet, opposite effects upon H and V are observed. In the case of the earth and the solar field an increase of the sun's field produces a secondary field relatively to its normal field, which is directed from geographical N to S,

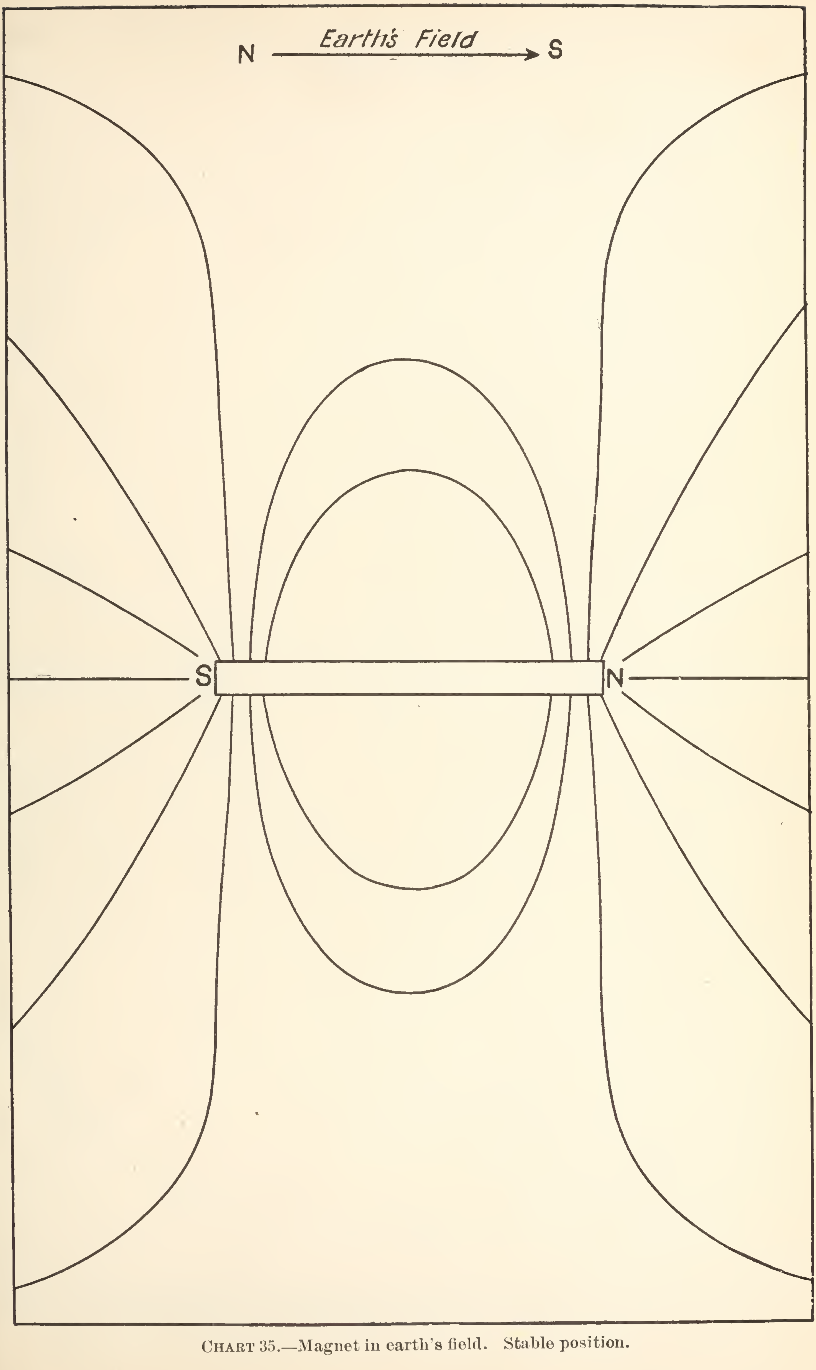

CHART 35.—Magnet in earth's field. Stable position.

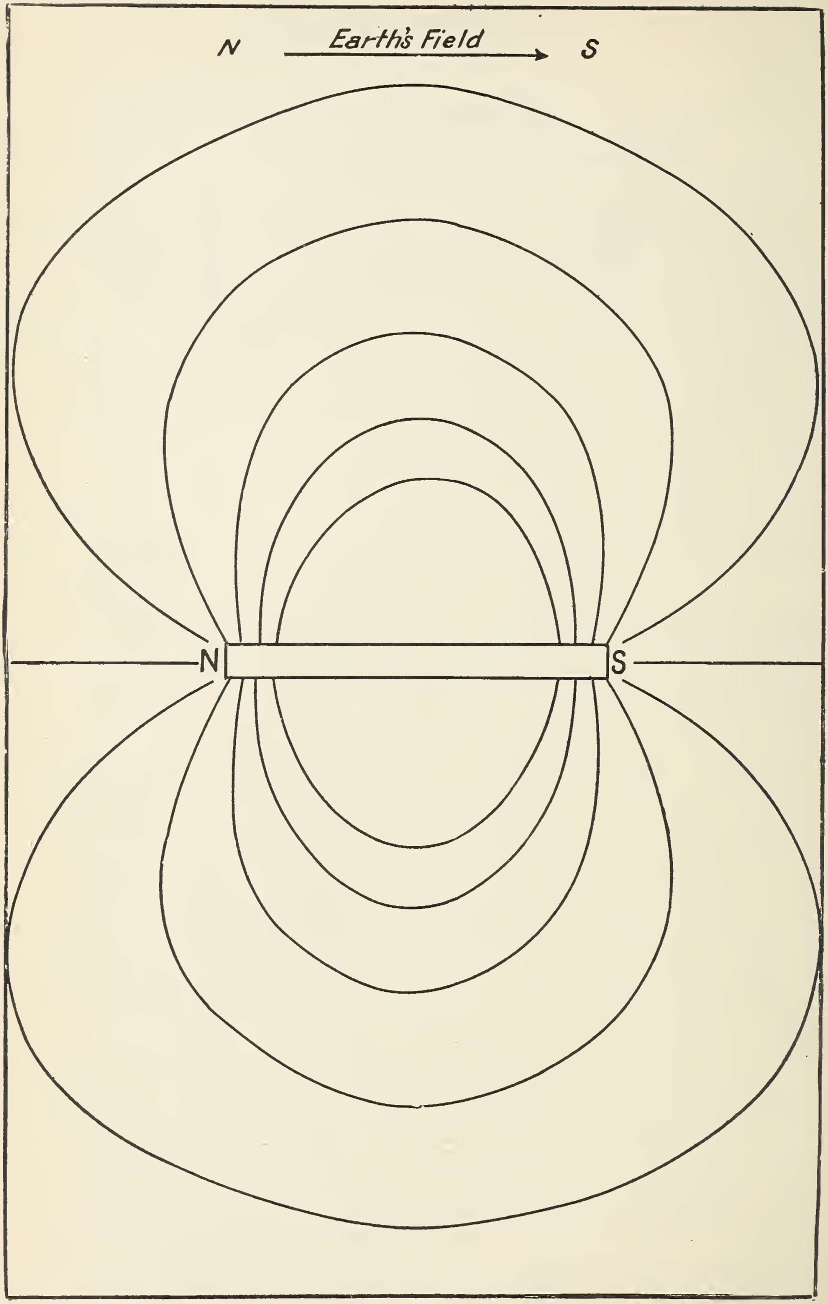

CHART 36.—Magnet in earth's field. Unstable position.

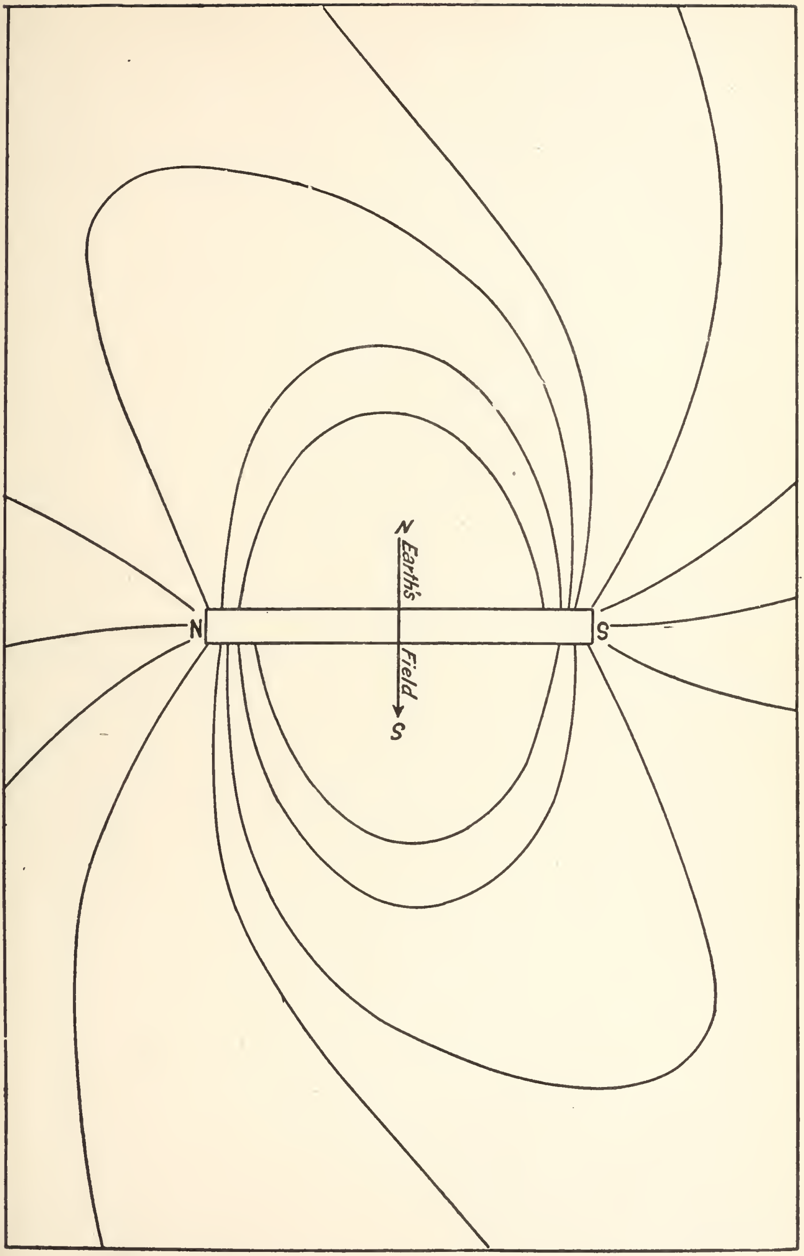

CHART 37.—Magnet lines distorted by earth's field. [N end to the left.]

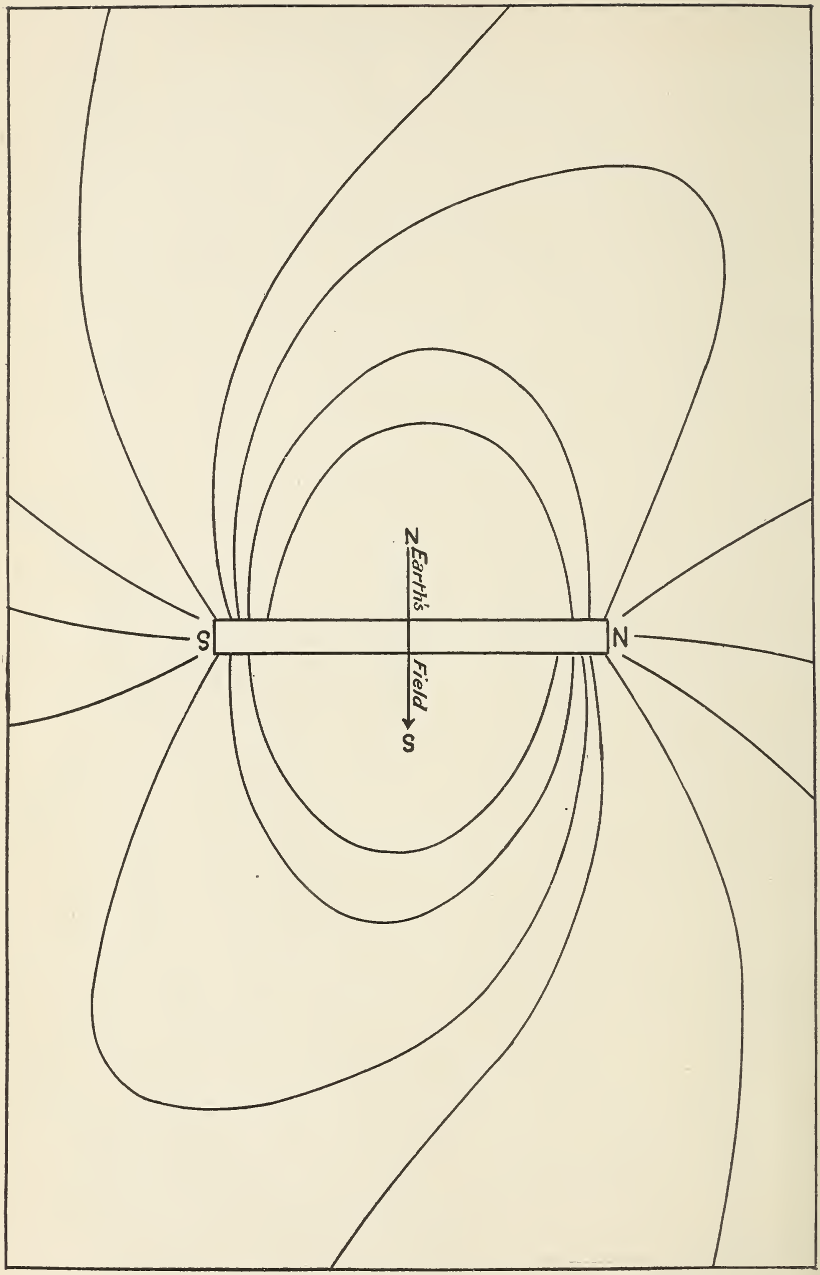

CHART 38.—Magnet lines distorted by earth's field. [N end to the right.]

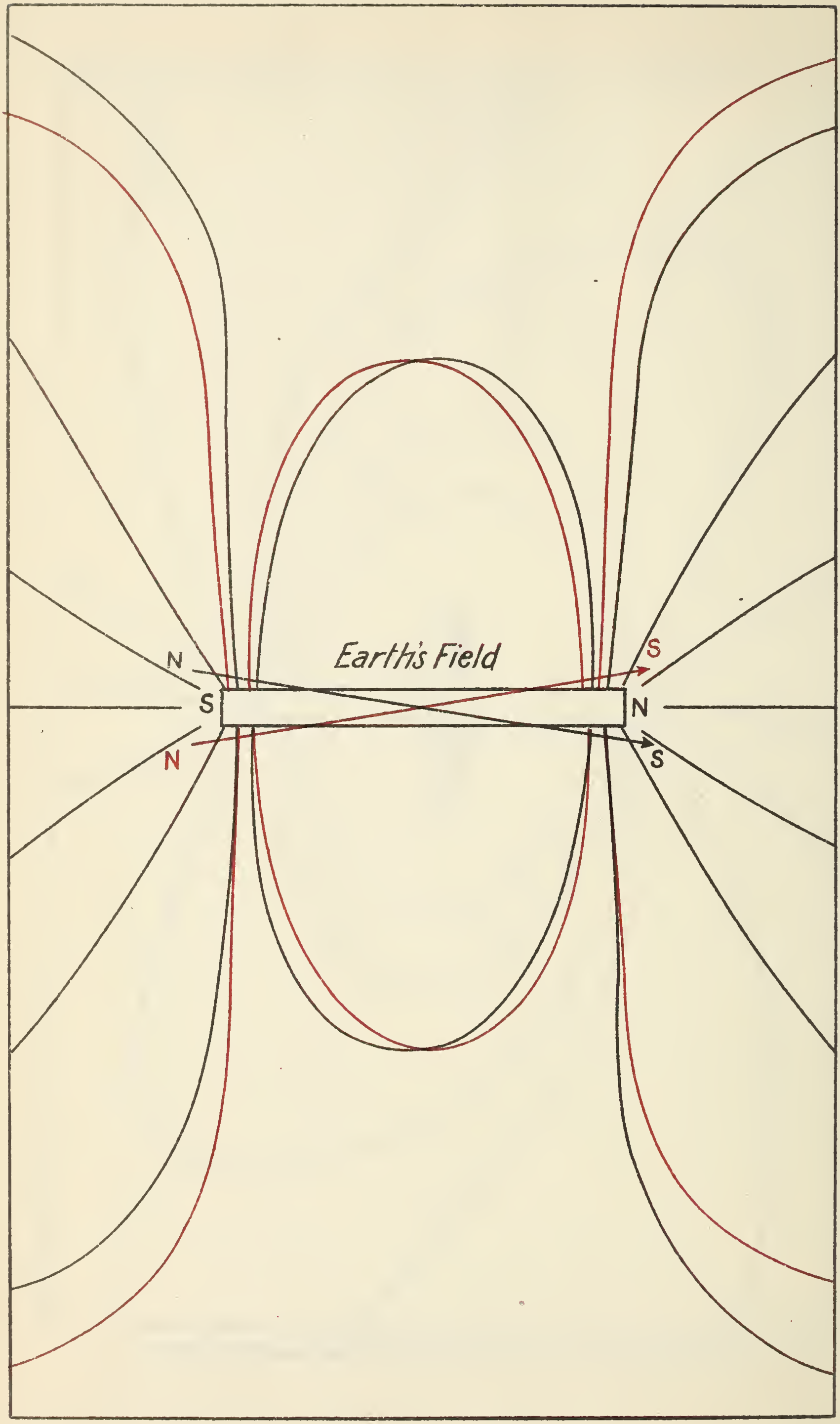

Chart 39.

and increases V, but diminishes H everywhere; a falling off of the solar field below its normal value produces just the opposite effect. The variable line of force traced out from day to day by means of the continuous photographic records in H. D. V., simply represents a secondary field directed from S to N or N to S, respectively, at different moments, according as H. D. V. at the instant observed are less or greater than the normal. The oscillations of the field, in waves, in irregular small vibrations or in perturbations, are thus observed as the simultaneous variations in H. D. V. over the entire earth. A decrease of H. is an increase of external force; an increase of V is an increase of the external field, and must always be so construed. As already mentioned, the great disturbances, having persistent durations of twenty-four hours or more, are observed to be always directed from the northward to the southward side of the ecliptic, and they occur simultaneously at all terrestrial stations. There is no other known cause of such a phenomenon capable of producing this remarkable result. Certainly no local meteorological conditions, and no rotation of the earth as a body, in a hypothetical medium of conducting capacity can account for these peculiar variations, unless the entire atmosphere of the earth, or unless the earth as a mass, has the variable motions corresponding to the observed vibrations of the needle taken from day to day. If, on the other hand, the magnetization of the sun is perturbed irregularly or periodically, then all the observed terrestrial phenomena follow in harmonious sequence.

Starting now from the unstable position of our magnet chart 36, let it swing half-way about, to right and left, till the axis of the magnet makes 90° with the external field. The instructive charts 37, 38 show the distortion of the medium, when the couples are in the positions of maximum power. The impulse to swing is in such a direction as to bring the N of the magnet to S of field, its stable position, as quickly as possible. A portion of the lines are open on opposite sides and drawing, the remainder are closed and pushing, thus distorting in two ways the normal forms of the curves. An opposite turn of 90° will bring the lines into the position of chart 38. When a magnet swings about an axis, its lines are playing through the rapidly varying curves of charts 37, 35, 38, if free to act in their own way; the magnet field may be forced through the forms 37, 36, 38 in succession.

Finally, when near the point of the stable equilibrium, a similar though smaller distortion of the curves takes place, even for slight displacements of the axis.

Chart 39 shows the two positions of the field when its axis is 10° on each side of the axis of the magnet; the undisturbed magnet lines may be drawn through their mean position. This is the practical case of the earth, as before explained, when the direct or inverse types respectively prevail. During the periods of direct type a left-handed couple prevails; and during the periods of inverse type a right-handed couple

CHART 39.—Magnet lines distorted by two couples. [Angle=10 degrees.]

prevails. The important deduction is that for the same external field the horizontal force of the earth's field is changed in one direction under one couple, and in the opposite direction for the other couple, when measured at any station as compared with the normal field at that place. The phenomenon of inversion is therefore an effect within the earth's field, of the presenting its lines to the direction of an impressed external field from the opposite sides, these couples being generated by the combined aspects of the axes of the earth and sun, together with the peculiar shape of the solar magnetic ovals. The typical curves of chart 8, derived from the observations, therefore find their necessary explanation in these circumstances, and carry with them the proof of the existence of a direct action of the solar magnetic field. To apply all these conditions to the solution of the force observed at any station at a given instant of time is possible, but very complex. Auxiliary tabulations of disturbances, like the terms of an orbit under perturbations, can be constructed to facilitate such a work, and it will become the province of the science of terrestrial magnetism to do so sometime. We may perceive that the Gaussian hypothesis of referring all these forces to an internal potential field of heterogeneous magnetization was imperfect. For the study of the secular variation, all these external terms must be eliminated before the Harmonic Analysis is applied to interpolations on the forces derived from an internal field. To recapitulate, we have, (1) the field from the earth's nucleus of only approximately known distribution; (2) the secondary distribution derived from the electro-magnetic field, varying only with the change of the axis of that field in latitude, including its couples; (3) the secondary distribution derived from the polar magnetic field, varying with the strength of the output from the sun, including its couples and the phenomenon of inversion. The rotation of the earth on its axis enabled us to eliminate the electromagnetic field, and also the local terms in the polar magnetic field, from the external couples; the rotation of the sun on its axis developed the normal type curve of relative intensity; the revolution of the earth in its orbit produced the inversion of the type curve, by the very peculiar conditions involved in the formation of the two systems of couples.

ELEMENTS OF THE SUN AND EARTH AS MAGNETS.

It may be convenient to have for reference the main features of the sun and earth as static magnets, derived in the case of the earth from I=0.079 C. G. S, and in the case of the sun from H=0.00035 C. G. S. at the distance of the earth. Logarithms are given in the last column.

TABLE 36.—*Magnetic elements of the earth in the C. G. S. system.*

R	Radius of earth	6.37×10^{8}	8.80414
R^2		4.058×10^{17}	17.60828
R^3		2.5848×10^{26}	26.41242
$\frac{4}{3}\pi$		4.18879	0.62209
I	Magnetization	0.079	8.89763—10
$V = \frac{4}{3}\pi R^3$	Volume of earth	1.083×10^{27}	27.03451
$M = VI. = -Fi R^3$	Moment	8.55×10^{25}	25.93214
$-Fi = +\frac{VI.}{R^3} = +\frac{4}{3}\pi I$	Interior force	0.33092	9.51972—10
$\Omega i = -Fi\, r \cos\theta$	Interior potential	$0.33092\, r \cos\theta$	
$\Omega e = -Fi R^3 \frac{\cos\theta}{r^2}$	Exterior potential	$8.55 \times 10^{25} \frac{\cos\theta}{r^2}$	
$Xe = +Fi R^3 \frac{(1-3\cos^2\theta)}{r^3}$	Exterior x-component (polar)	$8.55 \times 10^{25} \frac{(1-3\cos^2\theta)}{r^3}$	
$Ye = -Fi R^3 \frac{3\sin\theta\cos\theta}{r^3}$	Exterior y-component	$8.55 \times 10^{25} \frac{3\sin\theta\cos\theta}{r^3}$	
$Fn = -2 Fi R^3 \frac{\cos\theta}{r^3}$	Exterior normal component	$17.10 \times 10^{25} \frac{\cos\theta}{r^3}$	
$Ft = -Fi R^3 \frac{\sin\theta}{r^3}$	Exterior tangential component	$8.55 \times 10^{25} \frac{\sin\theta}{r^3}$	
$Fe = -Fi R^3 \frac{(1+3\cos^2\theta)^{\frac{1}{2}}}{r^3}$	Total exterior force	$8.55 \times 10^{25} \frac{(1+3\cos^2\theta)^{\frac{1}{2}}}{r^3}$	
$M = -\frac{3}{4} . Fi R^2$	Mass	1.7904×10^{17}	17.25294
$Q = -3\pi R^2 Fi$	Flow of force	1.266×10^{18}	18.10239
$N = -2\pi Fi R^3 \frac{\sin^2\theta}{r}$	Line of force	$5.37 \times 10^{26} \frac{\sin^2\theta}{r}$	26.73032
$\Omega = -Fi R^3 \frac{\cos\theta}{r^2}$	Equipotential surface	$8.55 \times 10^{23} \frac{\cos\theta}{r}$	

TABLE 37—*Magnetic elements of the sun (C. G. S.).*

R	6.968×10^{10} (433,000 miles)	10.84314
R^2	4.856×10^{21}	21.68628
R^3	3.384×10^{32}	32.52942
$4/3\pi$	4.18879	0.62209
I	824 from $\Delta H = .00035$	2.91593
V	1.417×10^{33}	33.15151
M	1.168×10^{36}	36.06744
—Fi	3451.62	3.53802
Ωi	$3451.62\ r\cos\theta$	
Ωe	$1.168 \times 10^{36} \frac{\cos\theta}{r^3}$	
Xe	$1.168 \times 10^{36} \frac{(1-3\cos^2\theta)}{r^3}$	
Ye	$1.168 \times 10^{36} \frac{3\sin\theta\cos\theta}{r^3}$	
Fn	$2.336 \times 10^{36} \frac{\cos\theta}{r^3}$	
Ft	$1.168 \times 10^{36} \frac{\sin\theta}{r^3}$	
Fe	$1.168 \times 10^{36} \frac{(1+3\cos^2\theta)^{\frac{1}{2}}}{r^3}$	
m	2.235×10^{25}	25.34924
Q	1.580×10^{26}	26.19857
N	$7.339 \times 10^{36} \frac{\sin^2\theta}{r}$	36.86562
Ω	$1.168 \times 10^{36} \frac{\cos\theta}{r^2}$	
Q_S/Q_E	1.2479×10^{8}	8.09618

TWO TYPES OF RADIATION.

We will now make some remarks upon the subject of radiation. From the beginning of my research I have had very definite ideas about the probable outcome of the solar-terrestrial problem, and have therefore adopted some terms that may not have been accepted by students generally in the meaning intended. Radiation can be defined as the transmission of energy from its source through the medium separating it from another body by merely transient disturbances of the medium at the intervening points. Radiation may be of many types. Two kinds alone concern this problem.

Adopting Heaviside's equations and notation, we have:

(1) The electromagnetic radiation from the sun:

$$W=v\,(U+T)=V\,\frac{(E-e_0)\,(H-h_0)}{4\pi}.$$

Its translational force or pressure is:

$$F=V\dot{D}B+VD\dot{B}=\frac{d}{dt}\,VDB=\frac{1}{v^2}\,\frac{d}{dt}\,VEH=\frac{1}{v^2}\,\frac{dW}{dt}.$$

The flux of energy is at right angles to the plane containing the electric force and the magnetic induction. The pressure per square centimeter is inversely proportional to the square of the velocity of propagation and to the time rate of change in the energy flux. The rays of propagation are the radii of the expanding spherical waves of electro-magnetic induction, and the length of path to the earth is about 92,800,000 miles.

(2) The polar magnetic radiation from the sun is of an entirely different nature, and is primarily the transient transmissions of the energy required to change a polar magnetic field of a certain strength to similar field of a different strength. The length of path to the earth is about 135,000,000 miles. As regards such a polar field, it is probably a very misleading conception to ever regard it as static, except in some of its effects. We may as well consider the electro-magnetic field static, because it exerts a steady pressure, but we have fortunately learned to analyze it as made up of immensely rapid vibrations, transmitting energy in wave motions. In a similar way the lines of force surrounding a common magnet are not at rest, but probably consist of vortex tubes, namely, electric currents rotating about the axis of the line of magnetic force with enormous rapidity. I take pleasure in referring to a careful graphical analysis of such a state of the medium in "Magnetische Kraftfelder," H. Ebert, Leipsig, 1896, which illustrates the views mentioned in this connection. The interaction of such vortex tubes affords a mechanical analogue which conforms very closely indeed to the observed physical effects, even if it does not represent the true state of the medium. Now the case of propagation of energy when the magnetic field is varying comes before us. Suppose

a soft iron bar surrounded by a spool of insulated wire, without current at first, lies within an ether medium in a quiescent state; by the action of the electric current, when suddenly impressed, the surrounding medium is set into vortical rotation by the transmission of lines of magnetic force from the iron bar. I can think of no truer word to describe this changing state of the medium than magnetic radiation of energy through it. This field may acquire a steady state, but it is essentially dynamic and not static. The word static in electro-magnetism is so far misleading that it ought to be abandoned, because it means only the steady state of an intrinsically dynamic field. In the same sense, though the sun may be said to maintain a steady magnetic field for short intervals, it is so far restless as to be practically transmitting energy incessantly in passing from one state of intensity to another. This transmission appears to be spasmodic, in large and small disturbances, and if Eschenhagen's observations of minute waves in the magnetic field can not be explained by pulsations derived from terrestrial sources, then likewise in small, quite rapid wave-like vibrations, which come very close to being a true periodic radiation. It must be said that the analysis of a polar field with a positive and negative pole is merely a convenience, and that both poles are probably sources and sinks simultaneously, though the positive is the source and the negative a sink only to the positive isolated pole upon which our analysis has been founded. This polar transient system may be examined more specifically, as it is less commonly understood. The following equations are rearranged from Heaviside's papers:

HEAVISIDE'S NOTATION.

	Electricity.		*Magnetism.*
c	Electric permittivity. $\mathbf{D}=\frac{c\mathbf{E}}{4\pi}$.	μ	Magnetic inductivity. $\mathbf{B}=\mu\mathbf{H}$.
k	Electric conductivity. $\mathbf{C}=k\mathrm{E}$.	g	Magnetic conductivity (fictitious).
$\mathbf{E}_1$	Force of field. $\mathbf{E}_1=(\mathbf{E}-\mathbf{e}_0)$.	$\mathbf{H}_1$	Force of field. $\mathbf{H}_1=(\mathbf{H}-\mathbf{h}_0)$.
$\mathbf{e}$	Motional force. $\mathbf{e}=\mathrm{V}q\mathbf{B}$.	$\mathbf{h}$	Motional force. $\mathbf{h}=\mathrm{V}\mathbf{D}q$.
$\mathbf{e}_0$	Intrinsic force.	$\mathbf{h}_0$	Intrinsic force.
$\mathbf{E}$	Electric force.	$\mathbf{H}$	Magnetic force.
$\mathbf{D}$	Displacement.	$\mathbf{B}$	Induction.
$\mathbf{C}$	Conduction current.	$\mathbf{K}$	Conduction current (fictitious).
$\mathbf{J}$	True electric current$=\mathbf{C}+\dot{\mathbf{D}}+\rho u$.	$\mathbf{G}$	True magnetic current$=[\mathbf{K}]+\dot{\mathbf{B}}+[\sigma\mathbf{w}]$.
ρ	Electrification. $\rho=\mathrm{div}\ \mathrm{D}$.	σ	Magnetification. $\sigma=\mathrm{div}\,\mathbf{B}$ (fictitious).
$\mathbf{u}$	Velocity.	$\mathbf{w}$	Velocity.
$\mathbf{Q}_1$	Joulean waste. $\mathrm{Q}_1=k\mathrm{E}^2=\mathrm{E}\mathbf{C}$.	$\mathbf{Q}_2$	Joulean waste (fictitious).
$\mathbf{U}$	Energy stored. $\mathrm{U}=\frac{1}{2}\mathrm{ED}=\frac{1}{2}c\mathrm{E}^2$.	$\mathbf{T}$	Energy stored. $\mathbf{T}=\frac{1}{2}\frac{\mathbf{HB}}{4\pi}=\frac{1}{2}.\frac{\mu\mathbf{H}^2}{4\pi}$.
$\mathbf{F}$	Polar force.	Ω	Magnetic potential.

FUNDAMENTAL EQUATIONS.

1. $\mathrm{curl}\ (\mathbf{H}-\mathbf{h})=4\pi\mathbf{J}=4\pi(\mathbf{C}+\dot{\mathbf{D}})=4\pi k\mathbf{E}+c\dot{\mathbf{E}}$.

2. $-\mathrm{curl}\ (\mathbf{E}-\mathrm{e})=4\pi\mathbf{G}=4\pi\left(\mathbf{K}+\frac{\dot{\mathbf{B}}}{4\pi}\right)=4\pi g\mathbf{H}+\mu\dot{\mathbf{H}}$.

Multiply the first by $(\mathbf{e}-\mathbf{E})$, the second by $(\mathbf{h}-\mathbf{H})$, and add,

3. $\mathbf{eJ}+\mathbf{hG}=\mathbf{EJ}+\mathbf{HG}+\frac{[(\mathbf{H}-\mathbf{h})\ \mathrm{curl}\ (\mathbf{E}-\mathbf{e})-(\mathbf{E}-\mathbf{e})\ \mathrm{curl}\ (\mathbf{H}-\mathbf{h})]}{4\pi}$

4. $\mathbf{eJ}+\mathbf{hG}=\mathbf{Q}+\dot{\mathbf{U}}+\dot{\mathbf{T}}+\mathrm{div}\ \frac{\mathrm{V}\ (\mathbf{E}-\mathbf{e})\ (\mathbf{H}-\mathbf{h})}{4\pi}=\mathbf{Q}+\dot{\mathbf{U}}+\dot{\mathbf{T}}+\mathrm{div}\ \mathbf{W}$.

Eliminate **H** and **E** successively in (1), (2).

5. $\text{curl}\,\frac{1}{\mu}\,\text{curl}\,(\mathbf{E}-\mathbf{e})+\text{curl}\,\mathbf{h}+4\pi k\,\dot{\mathbf{E}}+c\,\ddot{\mathbf{E}}=0$

6. $\text{curl}\,\frac{1}{c}\,\text{curl}\,(\mathbf{H}-\mathbf{h})-\text{curl}\,\dot{\mathbf{e}}+4\pi g\,\dot{\mathbf{H}}+\mu\,\ddot{\mathbf{H}}=0$

For $\mathbf{e}=0$, $\mathbf{h}=0$, and $\mathbf{g}=0$.

$$\left.\begin{array}{ll}7. & \text{curl}\,\frac{1}{\mu}\,\text{curl}\,\mathbf{E}+4\pi k\,\frac{d\mathbf{E}}{dt}+c\,\frac{d^2\mathbf{E}}{dt^2}=0\\ 8. & \text{curl}\,\frac{1}{c}\,\text{curl}\,\mathbf{H}\qquad\qquad\quad+\mu\,\frac{d^2\mathbf{H}}{dt^2}=0\end{array}\right\}\text{No impressed force in space.}$$

For $c=0$.

$$\left.\begin{array}{ll}9. & \text{curl}\,\frac{1}{\mu}\,\text{curl}\,\mathbf{E}+4\pi k\,\frac{d\mathbf{E}}{dt}=0\\ 10. & \text{curl}\,\frac{1}{k}\,\text{curl}\,\mathbf{H}+4\pi\mu\,\frac{d\mathbf{H}}{dt}=0\end{array}\right\}\text{Diffusion in metals of }\mathbf{E}\text{ and }\mathbf{H}.$$

For $k=0$.

$$\left.\begin{array}{ll}11. & \text{curl}\,\frac{1}{\mu}\,\text{curl}\,\mathbf{E}+c\,\frac{d^2\mathbf{E}}{dt^2}=0\\ 12. & \text{curl}\,\frac{1}{c}\,\text{curl}\,\mathbf{H}+\mu\,\frac{d^2\mathbf{H}}{dt^2}=0\end{array}\right\}\text{Wave propagation in gases of }\mathbf{E}\text{ and }\mathbf{H}.$$

MAGNETIZATION.

Intrinsic magnetization $=4\pi\,\mathbf{I}_1=\mu\,\mathbf{h}$.
Induced magnetization $=4\pi\,\mathbf{I}_2=4\pi\,k\,\mathbf{F}$.
Total induction $=\mathbf{B}=\mathbf{F}+4\pi\,\mathbf{I}_1+4\pi\,\mathbf{I}_2$.

$$\begin{aligned}&=\mathbf{F}+\mu\,\mathbf{h}+4\pi\,k\,\mathbf{F}.\\&=\mathbf{F}\,(1+4\pi k)+\mu\,\mathbf{h}.\\&=\mu\,(\mathbf{F}+\mathbf{h})=\mu\,\mathbf{H}.\end{aligned}$$

The actual $\mathbf{H}=\mathbf{h}$ (impressed) $+\,\mathbf{F}$ (polar) $+\,\mathbf{F}_1$ (current induced).

Some relations between circuital and polar forces.

		ELECTRIC CONDUCTOR.			
$\mathbf{E}_1=\mathbf{e}_1+\mathbf{F}_1$	$\mathbf{F}_1=-\nabla\,\mathbf{P}_1$	$\mathbf{C}=k\,\mathbf{E}_1$	$\text{div}\,\mathbf{C}=0$	$\text{curl}\,(\mathbf{e}_1-\mathbf{E}_1)=0$	$\rho_1=-\text{div}\,\mathbf{e}_1$
		DIELECTRIC.			
$\mathbf{E}_2=\mathbf{e}_2+\mathbf{F}_2$	$\mathbf{F}_2=-\nabla\,\mathbf{P}_2$	$\mathbf{D}=\frac{c}{4\pi}\,\mathbf{E}_2$	$\text{div}\,\mathbf{D}=0$	$\text{curl}\,(\mathbf{e}_2-\mathbf{E}_2)=0$	$\rho_2=-\text{div}\,c\,\frac{\mathbf{e}_2}{4\pi}$
		MAGNETIC CONDUCTOR.			
$\mathbf{H}=\mathbf{h}+\mathbf{F}_3$	$\mathbf{F}_3=-\nabla\,\mathbf{P}_3$	$\mathbf{B}=\mu\,\mathbf{H}$	$\text{div}\,\mathbf{B}=0$	$-\text{curl}\,(\mathbf{h}-\mathbf{H})=0$	$\sigma=-\text{div}\,\mu\,\frac{\mathbf{h}}{4\pi}$

CASES.

1. Curl $(\mathbf{H}-\mathbf{h})=0$, no current.

$\mathbf{F}=-\nabla\,\Omega$, polar magnetic field; and curl $\mathbf{F}=0$.

$\int\text{curl}\,(\mathbf{H}-\mathbf{h})=\mathbf{F}=-\nabla\,\Omega$; $\mathbf{H}=\mathbf{h}+\mathbf{F}$.

2. div $\mathbf{G}=0$. div $\mathbf{B}=0$. $\int\text{div}\,\dot{\mathbf{B}}=\text{div}\,\mathbf{B}=\text{div}\,\mu\,\mathbf{H}=0$.

3. Conditions: curl $(\mathbf{H}-\mathbf{h})=0$. div $\mu\,\mathbf{H}=0$.
Given μ and **h** to find **H**, the actual magnetic force.
div $\mu\,(\mathbf{h}+\mathbf{F})=0$. curl $\mathbf{F}=0$. div $\mu\,\mathbf{F}=-\text{div}\,\mu\,\mathbf{h}$.

I. Curl $\mathbf{h}=0$, curl $\mathbf{H}=0$. div $\mu\,\mathbf{H}=0$. $\mathbf{H}=0$ and $\mathbf{B}=0$.
If the impressed force be wholly polar there is no induction.

II. div $\mu\,\mathbf{h}=0$. div $\mu\,\mathbf{F}=0$. curl $\mathbf{F}=0$. $\mathbf{F}=0$. $\mathbf{H}=\mathbf{h}$. $\mathbf{B}=\mu\,\mathbf{h}$.
If the impressed force be wholly circuital there is full induction, and no polar force.

This shows that during transient adjustments of a magnetic field from one strength to another there are transient electric and magnetic currents.

Conductor, $\mathbf{Q} = \Sigma \mathbf{E}_1 \mathrm{k} \mathbf{E} = \Sigma \mathrm{e}_1 \mathrm{k} \mathbf{E}_1 = \Sigma \mathrm{e}_1 \mathrm{k} \mathrm{e}_1 - \Sigma \mathbf{F}_1 \mathrm{k} \mathbf{F}_1 = \Sigma \mathrm{e}_1 \mathrm{k} \mathrm{e}_1 - \Sigma \mathbf{P}_1 \rho_1 = \Sigma \mathbf{E}_1 \mathbf{C} = \Sigma \frac{1}{2} \mathbf{H}_1 \mathbf{G}_1$.

Dielectric, $8\pi \mathbf{U} = \Sigma \mathbf{E}_2 \mathrm{c} \mathbf{E}_2 = \Sigma \mathrm{e}_2 \mathrm{c} \mathbf{E}_2 = \Sigma \mathrm{e}_2 \mathrm{c} \mathrm{e}_2 - \Sigma \mathbf{F}_2 \mathrm{c} \mathbf{F}_2 = \Sigma \mathrm{e}_2 \mathrm{c} \mathrm{e}_2 - \Sigma \frac{1}{2} \mathbf{P}_2 \rho_2 = \Sigma \frac{1}{2} \mathbf{E}_2 \mathbf{D} = \Sigma \frac{1}{2} \mathbf{Z} \mathbf{G}$.

Magnetic medium, $8\mu \mathbf{T} = \Sigma \mathbf{E}_3 \mathrm{c} \mathbf{E}_3 = \Sigma \mathrm{h} \mu \mathbf{H} = \Sigma \mathrm{h} \mu \mathrm{h} - \Sigma \mathbf{F}_3 \mu \mathbf{F}_3 = \Sigma \mathrm{h} \mu \mathrm{h} - \Sigma \frac{1}{2} \Omega \sigma = \Sigma \frac{1}{2} \frac{\mathbf{HB}}{4\pi} = \Sigma \frac{1}{2} \mathbf{AJ}$.

$\mathbf{Q}$ = the work wasted in conductors as heat.

$\mathbf{U}$ = the electric energy stored in potential form in the dielectric.

$\mathbf{T}$ = the magnetic energy stored in kinetic form in the magnetic medium.

Proof of the last form.

Circuital displacement in a dielectric from electro-magnetic induction.

$$\operatorname{div} \mathrm{c}\mathbf{E} = 0. \qquad -\operatorname{curl} \mathbf{Z} = \mathrm{c}\mathbf{E} = 4\pi \mathbf{D}. \qquad \operatorname{curl} \mathbf{H} = \mathrm{c}\dot{\mathbf{E}} = 4\pi \mathbf{J}.$$

$$\operatorname{div} \mathbf{B} = 0. \qquad \operatorname{curl} \mathbf{A} = \mu \mathbf{H} = \mathbf{B}. \qquad -\operatorname{curl} \mathbf{F} = \mu \dot{\mathbf{H}} = 4\pi \mathbf{G} = \operatorname{curl} \frac{1}{\mathrm{c}} \operatorname{curl} \mathbf{Z}$$

$$\mathbf{U} = \Sigma \tfrac{1}{2} \mathbf{ED} = \Sigma \tfrac{1}{2} \frac{4\pi \mathbf{D}}{\operatorname{curl}} \frac{\operatorname{curl} \mathbf{E}}{4\pi} = \Sigma \tfrac{1}{2} \mathbf{ZG}. \qquad \text{Since, } \mathbf{Z} = -\frac{4\pi \mathbf{D}}{\operatorname{curl}}, \mathbf{G} = -\frac{\operatorname{curl} \mathbf{E}}{4\pi}.$$

$$\mathbf{T} = \Sigma \tfrac{1}{2} \frac{\mathbf{HB}}{4\pi} = \Sigma \tfrac{1}{2} \frac{\mathbf{B}}{\operatorname{curl}} \frac{\operatorname{curl} \mathbf{H}}{4\pi} = \Sigma \tfrac{1}{2} \mathbf{AJ}. \qquad \text{Since, } \mathbf{A} = \frac{\mathbf{B}}{\operatorname{curl}}, \mathbf{J} = \frac{\operatorname{curl} \mathbf{H}.}{4\pi}$$

Transient to final state.

Transient state $-\operatorname{curl} (\mathbf{E} - \mathrm{e}) = 4\pi \mathbf{G}$. $\qquad \mathbf{E}_0 = \mathrm{e} + \mathbf{F}_0 = \mathrm{e} - \nabla \mathbf{P}$ (Final).

Final state $-\operatorname{curl} (\mathbf{E}_0 - \mathrm{e}) = 0$. $\qquad \mathbf{F} = \mathbf{F}_0$. $\mathbf{G} = \mathbf{J}_2$. $\mathbf{J} = \mathbf{C} + \mathbf{D}$.

$$\Sigma \mathrm{e} \mathbf{J} = \Sigma \mathrm{e} \mathbf{J} + \Sigma \mathbf{F}_0 \mathbf{J} = \Sigma \mathbf{E}_0 \mathbf{J} = \Sigma \mathbf{E}_0 \mathbf{C} + \Sigma \mathbf{E}_0 \dot{\mathbf{D}} = \Sigma \mathbf{E}_0 \mathrm{k} \mathbf{E} + \Sigma \mathbf{E}_0 \mathbf{D} = \Sigma \mathbf{C}_0 \mathbf{E} + \Sigma \mathbf{E}_0 \dot{\mathbf{D}}.$$

$$\Sigma \mathbf{C}_0 \mathbf{E} = \Sigma \frac{\mathbf{C}_0}{\operatorname{curl}} \operatorname{curl} \mathbf{E} = \Sigma \frac{\mathbf{H}_0}{4\pi} (\operatorname{curl} \mathrm{e} - 4\pi \mathbf{G}) = \Sigma \mathbf{H}_0 \left(\frac{\operatorname{curl} \mathrm{e}}{4\pi} - \mathbf{G} \right) =$$

$$\Sigma \mathrm{e} \frac{\operatorname{curl} \mathbf{H}_0}{4\pi} - \Sigma \mathbf{H}_0 \mathbf{G} = \Sigma \mathrm{e} \mathbf{C}_0 - \Sigma \mathbf{H}_0 \mathbf{G}.$$

At each instant, $\qquad \Sigma \mathrm{e} \mathbf{J} = \Sigma \mathrm{e} \mathbf{C}_0 + \Sigma \mathbf{E}_0 \dot{\mathbf{D}} - \Sigma \mathbf{H}_0 \mathbf{G}$.

The time integral, $\Sigma \mathrm{e} \int \mathbf{J} dt = \Sigma \mathrm{e} \mathbf{C}_0 t + \Sigma \mathbf{E}_0 \mathbf{D}_0 - \Sigma \frac{\mathbf{H}_0 \mathbf{B}_0}{4\pi}$ = final state.

The work done $= \Sigma \mathrm{e} \int \mathbf{J} dt = \Sigma \mathrm{e} \mathbf{C}_0 t + 2\mathbf{U} - 2\mathbf{T}$.

Proof of the last steps.

Work done by actual forces=

$$\Sigma \int \mathbf{HG} dt = \Sigma \int \frac{\mathbf{H} \mu \dot{\mathbf{H}}}{4\pi} dt = \Sigma \int \frac{d}{dt} \left(\frac{\mathbf{H} \mu \mathbf{H}}{2.4\pi} \right) dt = \Sigma \frac{\mathbf{H} \mu \mathbf{H}}{2.4\pi} = \mathbf{T}.$$

Work done by impressed forces=

$$\Sigma \int \mathrm{h} \mathbf{G} dt = \Sigma \int \frac{\mathrm{h} \mu \dot{\mathbf{H}}}{4\pi} dt = \Sigma \frac{\mathrm{h} \mu \mathbf{H}}{4\pi} = \mathbf{T}_1 = \Sigma \frac{(\mathrm{h} + \mathbf{F}) \mu \mathbf{H}}{4\pi} = \Sigma \frac{\mathbf{H} \mu \mathbf{H}}{4\pi} = 2\mathbf{T}.$$

$$\mathbf{H} = \mathrm{h} + \mathbf{F} = \mathrm{h} + \operatorname{div} \Omega. \quad \mu \mathbf{H} = \mu \mathrm{h} + \mu \mathbf{F}. \quad \Sigma \mathbf{F} \mu \mathbf{H} = \Sigma \mathbf{F} \mu \mathrm{h} + \Sigma \mathbf{F} \mu \mathbf{F} = \Sigma \operatorname{div} \Omega \mu \mathbf{H} = 0.$$

$$\Sigma \int \mathrm{h} \mathbf{G} dt = \Sigma \int \mathbf{EJ} dt + \Sigma \int \mathbf{HG} dt = \Sigma \int \mathbf{Q} dt + \mathbf{T} = 2\mathbf{T}. \qquad \int \mathbf{Q} dt = \mathbf{T} = \mathbf{Q} \text{ mag.}$$

$$\Sigma \int \mathrm{e} \mathbf{J} dt = \Sigma \int \mathbf{HG} dt + \Sigma \int \mathbf{EJ} dt = \Sigma \int \mathbf{Q} dt + \mathbf{U} = 2\mathbf{U}. \qquad \int \mathbf{Q} dt = \mathbf{U} = \mathbf{Q} \text{ elect.}$$

One-half the energy of the transient currents is expended as heat and the other half as the kinetic magnetic energy of the new state of the field.

SUMMARY STATEMENT.

1. Electrostatic case, magnetic energy vanishing, $\Sigma eC_0t + 2U = \text{Work}$.
2. Magnetic case, electrostatic energy vanishing, $\Sigma eC_0t - 2T = \text{Work}$.
3. Joule's heat, electrostatic and magnetic energy, $\Sigma eC_0t + U - 3T = \text{Work}$.

The case of the polar magnetic field from the sun is the second, for which the work of the forces within the sun is supposed to be,

$$\text{Work of impressed forces} = \Sigma eC_0t - 2\ T.$$

The first term is the Joule's heat of the final electric current set up, whatever transient electric currents may have occurred within the body of the sun, but may be laid aside from consideration in the external magnetic field.

$$\text{That part of the work} = -\int Qdt - \tfrac{1}{2}.\frac{\mu\ H^2}{4\ \pi}.$$

We have two remarkable results, that the work done in this case is expended—

(1) In cooling the medium throughout the interplanetary magnetic field, as was shown to be the observed fact at the earth from the discussion of the meteorological elements.

(2) In setting up a magnetic field.

Since it has been shown that the work expended in setting up final states of currents of electricity is diminished by the term 2 T from that which it would be in setting up electric currents in the sun without any external magnetic field, the inference follows that less work is required to bring about equilibrium states on the sun, when once disturbance occurs in its magnetization or in its electric condition, than would be the case if no external magnetic field existed outside it. This seems most remarkable, but it is concluded that the cooling of the external medium and the increase of the external magnetic field calls for less work in the sun to readjust its forces to normal states than would have been the case if they did not thus exist and operate. Hence, instead of being an argument against the direct magnetic action of the sun, the observed external field at the earth becomes the physical verification of the fact that the sun is a highly magnetized body. It adjusts itself by this mode of operation and expends the minimum work. This inference stands so directly contradictory to the conclusions expressed by Lord Kelvin in his anniversary address (Nature, Vol. XLVII, p. 108), and which have been quoted against the hypothesis of the direct magnetic action of the sun, that it may be proper to note it in connection with that statement.

RECOMPUTATION OF SOLAR VALUES OF E. H.

On page 402, Vol. II, Electricity and Magnetism, Maxwell gives a computation of the electric and magnetic forces developed during the transmission of energy in sunlight, using Pouillet's data. Since Lang-

ley's determination of the solar constant gives nearly twice as great a value as Pouillet's, it will be worth while to recompute the values of E and H, the maximum amplitudes developed in sunlight. Some other derivative numerical values are added.

The corresponding quantities in the polar field are only transient, very variable, and are therefore not available except when integrated. To do this practically is not now possible, since the observational data, referring to the absorption of energy in the atmosphere, is not yet freed from the convective action of currents derived from the general circulation.

TABLE 38.—*Recomputation of the electric and magnetic forces.*

[E and H for Langley's constant of solar energy.]

Data for the transformations.	Thomson.	Intermediate.	Langley.
Constant of solar energy in calories	17.037	25.00	30.00
(1 horsepower $=10\frac{7}{16}$ calories.)			
Solar constant in horsepower per square meter per minute	1.632	2.395	2.874
(1 horsepower=550 foot-pounds per second.)			
Solar constant in foot-pounds per second	897.7	1317.3	1580.8
(1 square meter=10.7641 square feet.)			
Solar constant in foot-pounds per second on 1 square foot = energy of strong sunlight.	83.4 (Maxwell)	122.4	146.9
(1 foot-pound=0.13825 kilogram meter.)			
Solar constant in kilogram meters per second on 1 square meter.	124.1 (Poincaré)	182.1	218.5
(Velocity of light $=9.838\times10^8$ feet per second.)			
Energy in a cubic foot of sunlight in foot-pounds: or the pressure on 1 square foot placed normal to ray.	.0000000848 (Maxwell)	.0000001244	.0000001493
(Velocity of light $=2.9986\times10^8$ meters per second.)			
Energy in a cubic meter of sunlight in kilogrammeters; or the pressure on 1 square meter placed normal to ray.	.0000004139 (Poincaré)	.0000006074	.0000007288
Hence, E electric force	5.673×10^8	6.872×10^8	7.528×10^8
H magnetic force	0.01892	0.02292	0.02511

(Maxwell used V=310900000 meters per second.)

$$\mathbf{E}=7.5\times10^8 \text{ C. G. S.}=7.5 \text{ volts.}$$

$$\mathbf{H}=0.02500 \text{ C. G. S.}$$

$$\mathbf{U}=\frac{c\mathbf{E}^2}{8\pi}=\frac{\mu\mathbf{H}^2}{8\pi}=\mathbf{T}=0.000025 \text{ C. G. S.}$$

$$\mathbf{W}=\mathrm{v}\,(\mathbf{U}+\mathbf{T})=\mathrm{V}\mathbf{EH}=1.875\times10^7 \text{ C. G. S.}$$

$$\mathbf{F}=\frac{1}{v^2}\frac{d\mathbf{W}}{dt}=\frac{\mu c}{v^2}\frac{d}{dt}\,\mathrm{V}\dot{\mathbf{D}}\mathbf{B}=\mathrm{V}\dot{\mathbf{D}}\mathbf{B}+\mathrm{V}\mathbf{D}\dot{\mathbf{B}}$$

$$\mathbf{F}=\mathrm{V}\,(k\mathbf{E}+\frac{c}{4\pi}\dot{\mathbf{E}})\,\mu\mathbf{B}+\frac{c}{4\pi}\,\mu\mathrm{V}\mathbf{E}\dot{\mathbf{H}}=\mathrm{V}\mathbf{JB}+4\pi\mathrm{V}\mathbf{DG}.$$

F=Electromagnetic force + magnetoelectric force, these being mechanical or translatory pressures.

The electromagnetic force can exist in steady states, and it is accompanied by dissipation of energy. The magnetoelectric force can exist only in the transient states. Hence the electromagnetic radiation exerts a steady pressure along the ray of sunlight. The magnetoelectric radiation emits temporary mechanical pressures during the changing of the strength of the polar field of the sun. We may therefore properly speak of the two radiations from the sun, provided the distinction between these two kinds is carefully maintained. To confuse them is an error of analysis.

A purely physical question now remains to be answered. If a magnetic polar line consists of a magnetic force parallel to the direction of **B** and a system of circular electric currents surrounding it in a vortex ring (see Barker's Physics, p. 803; Ebert's Kraftfelder, chapter 8, and other authors), how are these forces related to changes of temperature of a medium such as the atmosphere? We know that an increase of temperature of the air diminishes the magnetic force of a magnet placed within it, and vice versa. Now, what goes on to do this? The chapter of J. J. Thomson, "Applications of dynamics to physics," on Temperature, No. VI, is very instructive, and should be carefully considered. Till this subject is fully worked up in the laboratory, we may refer to it as one of the unsolved problems as regards the principles of radiation.

Closely connected with this inquiry is a second problem: What are the peculiar mechanical forms of the variations in the vortical system which permits the transfer of energy from the sun to the earth, through so great a distance as 135,000,000 miles, for example? The treatment of the forces as a problem of dynamics instead of statics is apparently the proper method of procedure. Furthermore, the question arises, What is the cross connection between the electromagnetic and the polar magnetic fields, especially in the problem of the dissipation of energy in atmospheric absorption and radiation, accompanied by changes in the wave lengths? All these topics lie beyond the province of this bulletin, but they are nevertheless of much importance.

FUNCTIONAL VARIATIONS IN THE MAGNETIC AND METEOROLOGICAL ELEMENTS.

In view of this hiatus in knowledge of the laws of physics, also considering the total lack of magnetic observations in the Northwest of the United States, and having regard to the components of temperatures and pressures derived from direct energy, intermingled with air in convection currents, it is a most difficult matter to determine what the functions between variations in the magnetic field and the corresponding changes in the meteorological elements of the air really are. As an approximate solution, I have assumed that the synchronism, taken year by year, between these systems is proportional. This amounts to supposing that if the sunlight field acts alone, the mean annual values would show no secular changes, and that therefore the observed simultaneous variations are due to the polar magnetic field alone. Hence the changes are proportional to the required functional relations. From this data (see Table 29) the following results have been derived:

Variations taking place simultaneously:

In the maximum field (auroral belt)	0.000050 C. G. S.
In the European field (also United States)	0.000010 C. G. S.
In the external coronal field (near the earth)	0.000030 C. G. S.

To these correspond, when the above changes are maintained for a year, as is the case in the northwest of the United States and West Canada:

Change in the mean annual pressure, an increase,	0.02 inch.
Change in the mean annual temperature, a decrease,	2° F.
Change in the mean annual pressure amplitude,	0.01 inch.
Change in the mean annual temperature amplitude,	0.2° F.

During certain years in the Dakotas the pressure averages higher and the temperature lower; the average swing of the oscillations from high to low and from warm to cold, taken day by day, is less; and this takes place in years of increased magnetic force from the coronal field in the proportion given above.

In order to show how widely these changes occur from year to year, it is found in the sun-spot cycle 1878–1890 that the following changes took place in those districts:

Range in the European magnetic horizontal component,	0.000060 C. G. S.
Range in the external solar coronal field,	0.000180 C. G. S.
Range in the maximum solar (auroral) field,	0.000300 C. G. S.
Range in the northwest (the Dakotas) pressures,	0.10 inch.
Range in the northwest temperatures,	7° F.
Range in the northwest pressure amplitude,	0.06 inch.
Range in the northwest temperature amplitudes,	1° F.

These relations may need modifications whenever the scientific data warrants an improvement, but they serve to show the general connection between the various quantities involved.

THE GENERAL RELATIONS TO THE GAUSSIAN POTENTIAL OF THE EARTH AND ITS SECULAR VARIATIONS.

It is evident that the general position taken in this bulletin is in accord with the results of the recent analytical calculations of the earth's potential from observations, in so far as it concludes that there is a varying potential outside the earth impressed upon the inside potential. There is, however, a wide divergence in regard to the source of the external field. The opinions quoted are quite uniform in the view that its seat is to be found in the hypothetical electric currents of the rarefied upper atmosphere. Our result is to attribute it to two external fields, having their seat in the sun, interacting upon each other and upon the earth's internal potential. It is clear that these fields possess all the properties required by the analysis of the observations, as herein described, to account for the phenomena. The electric air currents are merely equivalent to the magnetic fields, and in themselves these equivalents have no advantage over the other in the discussion, unless they can be primarily shown to really exist.

Briefly, the argument stands as follows: Admitting that electric currents exist in the atmosphere, as must be the case if there is any

variation of the magnetic potential, we have shown that the magnetic fields, in addition to that effect, exhibit such peculiar properties as to render the explanation intelligible only by placing their seat outside the earth's atmosphere, and specifically in the sun. If the source of the variations under discussion is only within the earth's atmosphere, how is the periodicity and the inversion found in the observations to be accounted for? Also, how is the eleven-year system of synchronous variations of the earth and the sun to be explained, unless we suppose that the earth has power enough to change the state of the sun itself, an idea which seems inadmissible. Several objections to ascribing the variations of the earth's field to the atmospheric convection currents of meteorology have been already mentioned, and these must also be suitably overcome. It is admitted that during the mutual readjustments of the magnetic fields currents of electricity exist throughout the atmosphere; also a change in the wave lengths of the electromagnetic external fields may be a source of the atmospheric electricity; but these subjects must be more fully studied, if possible, before a decisive statement can be offered. The synchronism between the solar and the terrestrial phenomena, the periodicity and inversion of type in the polar field, the peculiar distribution of the magnetic vectors in the electromagnetic field, are therefore the chief points to explain on the atmospheric electric-current theory. These currents, as well as the earth electric currents, are necessary consequences of the interaction of the three fields described, including their own variations in strength and the induced variations due to motion of the planet. But it is hardly possible to consider such electric currents as the true source of all the phenomena heretofore mentioned in detail.

GENERAL SUMMARY.

A summary of the contents of this bulletin indicates that the old problem of the causal connection between certain solar and terrestrial phenomena has been brought one stage nearer its solution. The investigation was carefully founded upon the observations of the magnetic and meteorological elements, and it has been thought proper not to encumber the exposition with much computation, though the necessary working formulæ are collected together for the convenience of the reader. No hypothesis was presupposed in the discussion of the observations which lead to the residuals obtained, but certain deductions were afterwards drawn from them which seem to be warranted by the facts of the case. Among the leading conclusions thus deduced from the observations may be mentioned:

1. The determination and practical use of a period of the synodical rotation of the sun, 26.67928 days, which seems to hold good for at least a half century.

2. The construction of a typical curve, which represents the relative intensity of the normal magnetic field of the sun at the distance of the earth.

3. The detection of this curve in solar and terrestrial phenomena, together with its inversion during the passage of the earth about the sun.

4. The statement of several arguments in favor of the direct magnetic action of the sun upon the earth.

5. The vectors of the lines of the solar magnetic field as distorted by the earth, and the conclusion that the outer shell of the earth is alone permeable to such lines of force.

6. The analysis of the diurnal variations of the needle, and the conclusion that the electromagnetic field of the sun acts like a uniform magnetic field upon such a configuration as the earth, independent of the coronal field, its axis of magnetization being at right angles to the direction of the field.

7. The inference that the earth's atmosphere is thrown out of equilibrium by a uniform heating on the tropical zones, together with an intermittent cooling upon the polar cap, the latter being caused by the direct magnetic field of the sun.

8. An outline in Bulletin 20 of the scheme of the relation of these systems of force to the circulation of the air, whereby a modification of the commonly accepted theory of cause of the formation of cyclones is suggested.

9. The cloud work now being prosecuted by the Weather Bureau will probably afford the data necessary to settle this branch of the problem.

10. It is very desirable that magneticians should establish some permanent observatories, especially in the polar regions of North America and the northwestern United States, in order that these problems may be more efficiently studied.

This bulletin may properly be concluded with an estimate of the probable value of this magnetic polar field in forecasting. No negative or adverse opinions can be accepted as final regarding its practical uses, because it has not been tried; while, on the other hand, it has been shown that the magnetic field is intimately associated to some extent with the production of the weather conditions. The force is itself extraordinarily sensitive, too much so for very simple operations and uninstructed observers, till our instruments are modified. It has a great range of operation in space and time, being in fact the golden thread of continuity running through the otherwise apparently lawless succession of weather variations. The mean curve has a forecasting power to the amount, approximately, of 75 per cent in the Dakotas, so far as the broad features of the highs and lows are concerned, and it is especially useful in the classification of all meteorological data. It contains a very promising method of finding a solution of the problem of

the causes of the marked seasonal changes of the weather in the United States. Next to the barometer and thermometer a magnet is the most valuable instrument in meteorological science. There are doubtless difficulties to overcome in order to reduce the subject to its practical application in the service of the Weather Bureau, but there are grounds for hoping that this can be done.

The renewed interest during recent years in the subject of cosmical magnetism, joined to the great advancement in the general knowledge of electricity and magnetism, warrants the expectation that much practical advantage can be gained by a complete understanding of the laws of this department of natural science.